THE DEVELOPMENT OF ADVANCED MANUFACTURING TECHNIQUES IN THE PRODUCTION OF LARGE TRANSPORT OR STORAGE FLASKS FOR RADIOACTIVE MATERIALS

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SUMMARY

Large Nuclear Transport and Storage Flasks (50 Tonnes +) are constantly being developed in an attempt to optimise designs to suit the particular requirements of a given payload. Flask sizes are also increasing in an effort to reduce frequency of journeys, footprint size for storage and the requirements for multiple handling. These factors are constrained by the capabilities of utilities to handle these increased weights (sometimes in excess of 100T laden,) and the transportation limitation of road and rail gauges. There are other limitations, not least amongst which are those of the manufacturer and the cost of implementation. Since ultimately any design must follow a manufacturing route it is critically important that the designers follow a whole life least cost solution. The achievement of this methodology is greatly assisted by an involvement from the manufacturers and also their suppliers of major or technically difficult components. This paper will review the history of UK flask design, the applicable manufacturing techniques employed and some areas that were developed during this process. This section will concentrate on three particular designs of flask, cuboid, cylindrical thin walled lead lined and thick walled neutron shielded. The paper will consider various aspects of each design and review the relative difficulty in achieving the desired end result. As a follow up to this, the paper will address the new breed of transport and storage flasks, those above 80T carrying high level vitrified waste or spent fuel. These flasks not only need a design and manufacturing route of the highest integrity but also special requirements due to their size and weights. The paper will consider key areas that have the most significant impact on the "manufacturability" of designs both from a cost and technical demand standpoint. Critical areas under consideration will be the welding on the flask, focusing on recent developments that have been undertaken by British Steel Engineering with suggestions being made as to how easier manufacturing routes could have been achieved through earlier collaboration between the designers and manufacturer.

Finally the paper will show how a collaborative approach between the ultimate client, designers and manufacturers has resulted in more cost effective, safe end products.

HISTORY

In 1958 the UKAEA involved British Steel Engineering in the very first flask for carrying spent nuclear fuel. These flasks were a large cast iron structure with longitudinal fins. See Figure 1

Fig 1 Early Cast Iron Flask

It can be seen from the quality of finish and other features that the requirements of nuclear fuel transport have developed significantly since then. However it should be noted that this standard of manufacture was as high as could be expected given the examination techniques prevailing at the time. This early contact with the UK Nuclear industry has developed into a long term relationship of understanding and co-operation with British Steel Engineering having produced most models and configurations of transport flask used in the UK.

The follow up models to this were the first generation Magnox flasks for the Central Electricity Generating Board, CEGB (1961). These flasks were cuboid in design due to the short length of fuel element and drive towards high capacity. These were of 15" plate construction with dove tail joints being held in place with a relatively small, 25mm seal weld. The lids were of twin plate construction with a thin austenitic stainless steel plate being plug welded across the inside of the main lid face. No stainless steel cladding of seal faces was applied at this time, and this did not come into effect until 1966 as the Magnox designs were further modified.

The early use of forgings in flasks was gained also in 1966 with the UNIFETCH "L" series flasks which had both forged lids and bases. These flasks were quickly followed in 1967 by the first Excellox flasks to be manufactured by British Steel Engineering the XL1. These were cylindrical, of rolled plate design 3½" thick, with radial outer fins. Bulk shielding was gained at this time with the introduction of stainless steel shrouded lead liners. One year later British Steel Engineering received an order for the second generation of Magnox flasks, and one of their most significant technological challenges. This time the 15" plates were not dove tailed but full penetration electro slag welded.

The Electro Slag Welding Process gives a high deposition rate but with a high heat input into the joints it also induces considerable plate movement due to thermal distortion. To allow for this factor joints were set out of square prior to welding knowing that the process would restore perpendicularity. Associated also with the high heat input and slow cooling rate of the electro slag process is a coarse columnar grain structure, typically Widmanstaetten in form. In order to obtain impact resistant properties a single or double normalising heat treatment was thus required - at further expense. Details of this process in production are shown in Figure 2. A similar process of heat treatment was adopted for the outer fins.

Cylindrical and cuboid designs of this nature were relatively static throughout the 1970's with the Excellox 3 range and NTL 11/14 flasks. The major development during this time was that of a more efficient means of stainless steel cladding through semi and fully automated routes.

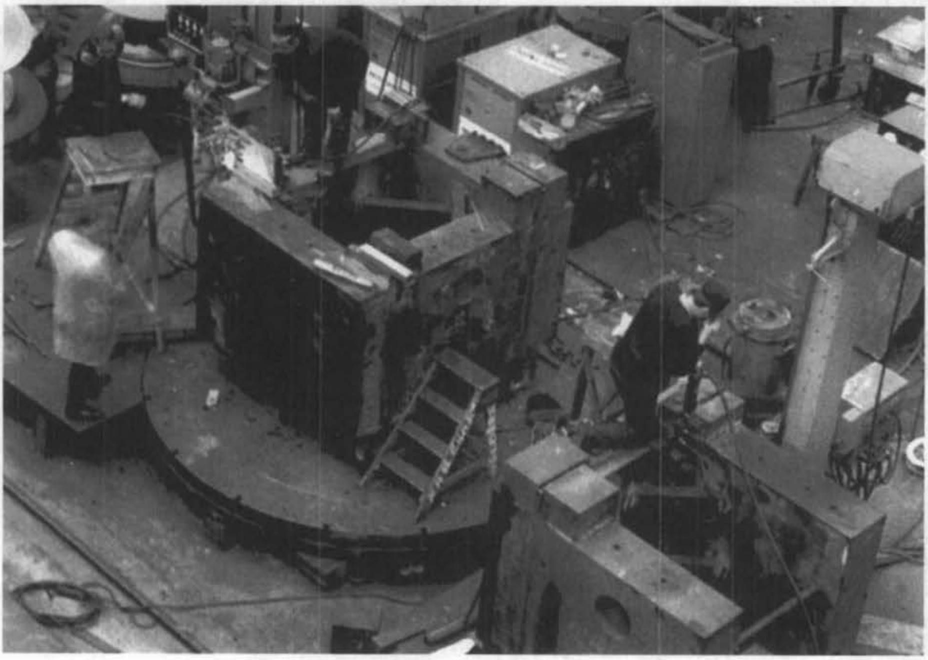


Fig 2 Early Electro Slag Welding

Initially austenitic stainless steel cladding was applied using the conventional manual metal arc (SMAW) process, with standard and then where possible high deposition rate electrodes. Development of submerged arc wire, and strip cladding followed as requirements for coverage of larger surface areas appeared, and MIG and flux cored arc welding were utilised for non automatic applications. More recently submerged arc welding using an electro slag strip cladding head has proven a reliable and consistent high quality process. In most cases typically an 18-8 (18% chromium, 8% Nickel) deposit has been required.

The most significant design change to affect manufacturing was that made in 1980 with the usage of a single piece monolithic forging on the third generation of Magnox flasks. This design route alleviated the need for the full penetration welds used previously , and gave a subsequent reduction in fabrication hours. However, the forgemaster could only provide a block forging with a small central indentation punched out. This block weighed approximately 70T, 20T of which was immediately machined away by the manufacturer, only to have a further 5T of stainless steel added back on.

Comparative manufacturing costs including procurement went up by approximately 50 - 70%, with the time taken for the receipt of forgings often increasing project time scales by 4 - 6 months over a plated option. The same process was similarly used during the late 1980's for the production of MK2 AGR Fuel flasks (A2). See figure 3. However a further complication for the manufacturers with this project was the flexible Lid Seal Member (LSM). This was a thin stainless steel plate that sat between the lid and flask body. The aim of this plate was to maintain containment in the unlikely event of an incident causing distortion between the body and lid. The difficulty however was in achieving an initially "flat" LSM plate, as the movement due to self relieving of stainless steel is difficult to control as it is worked. This factor created problems during manufacture, but still remains a feature in some of today's designs.

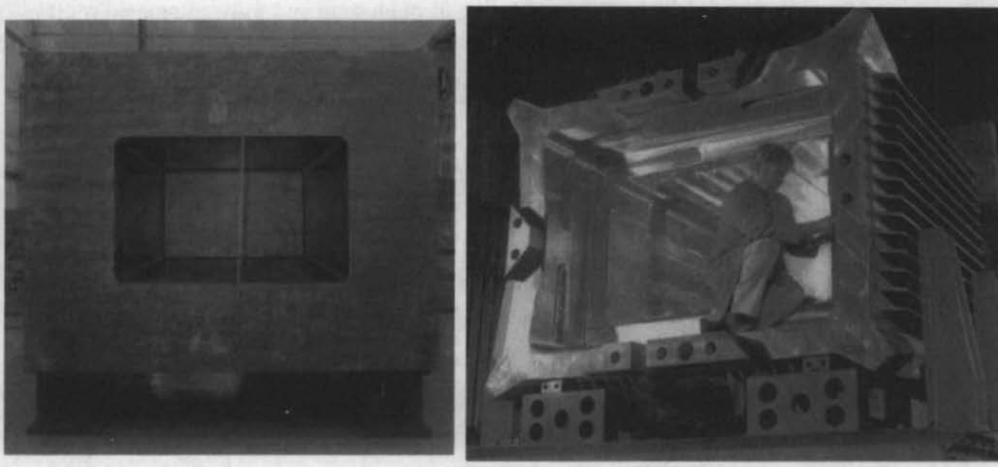


Fig 3 A2 Body Forging & Almost Complete Flask

The use of thick walled forgings for cylindrical flasks commenced in the early 1990's at BS Engineering with the introduction of BNFL's Excellox 6 flask. A major driver in the move from lead lined flasks to monolithic bodies was the need to carry higher burn-up fuel with additional Neutron Shielding. As lead is a relatively poor thermal conductor, heat dissipation was limited with newer fuels and fuel degradation may have occurred.

These new designs still utilise a full penetration body to base (also a forging) weld (See Figure 4). This used a submerged arc procedure, which whilst expensive to develop has since given 100% defect free results in subsequent production use. Charpy-V-Notch and Pellini properties at temperatures below -40°C have become the norm, and good fracture toughness (CTOD Values) have also been verified. Elevated temperature properties at 300°C are a further requirement. This weld was some 330 mm deep over an external circumference of 5.0 m. The weld was a continuous 7 day process laying 573 weld runs and 2 miles of weld! The end result was fully radiographed, Ultrasonically examined and Magnetic Particle inspected. No reportable defects were discovered in 725kg of weld metal and British Steel Engineering now routinely carry out this procedure with similar results.

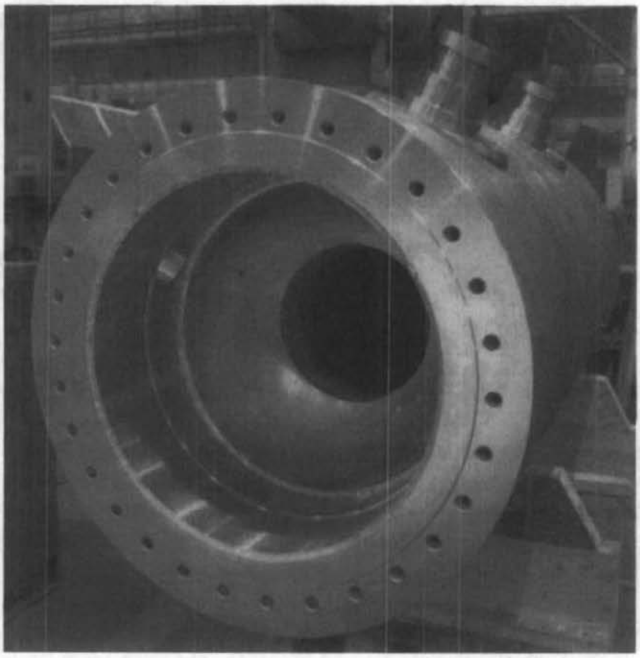


Fig 5 Ball Valve Flask

Fig 4 Section Through Test Piece Body to Base Weld Showing Runs

Although this brief review covers the majority of the concepts and difficulties seen over the period 1960 - 1992, note should be made of those designs, that found favour for a few specific applications including:

- Ball Valve Flasks, which as the name implies utilise a ball valve arrangement for the loading and discharge of wastes (See Figure 5).
- Speroidial Graphite Cast Iron Flasks, which although popular in Europe have never really found favour in the UK, US or Japan.
- Flask upgrades, for modified duties of service. A current application of this has recently been completed by BS Engineering.

The relative difficulties for manufacturing flasks of this nature are however a discussion for a future date.

MODERN FLASK DESIGN

Modern flasks have changed in construction from earlier designs for two main reasons:

- Fuel and waste characteristics have changed and hence designs have had to cater for this.

- Advances in analytical techniques in both the evaluation of flask designs and in the resultant effect on the environment have allowed targeted design improvements over many years. This allied to developments in manufacturing processes, quality assurance and material formation has enabled superior flask designs to be more readily available and constructed.

If it is accepted that the progress to date has yielded a good if not wholly optimised solution to the problem of storage and transport of radioactive wastes then the remaining designs contain the following elements:

- Thick Walled Gamma Shielding, either from forged carbon steel or cast iron bodies.
- Heat dissipation through the above, and externally attached cooling fins.
- Neutron Shielding via outer surface barriers.

If the last is taken first, British Steel Engineering encountered this feature in 1984 with the NTL 15 design of flask which has an outer copper finning arrangement. The neutron shielding applied was a pre-cast polyester resin containing an aluminium, polypropylene powder, zinc borate mix. These blocks were machined to size and put in place at British Steel Engineering's works. Later examples of shielding material were mixed by British Steel Engineering personnel and poured onto the relevant areas of the flask where they were contained during solidification. These materials included:

- Borosilicone for A2 flasks
- Kobesh (Licensed by Kobe Steel) for the Excellox 6 flasks
- Bisco on the NFT 12, & 22B ranges of flasks, manufactured in conjunction with Kobe Steel for Tokyo Electric Power Company (TEPCO). See Fig 6.

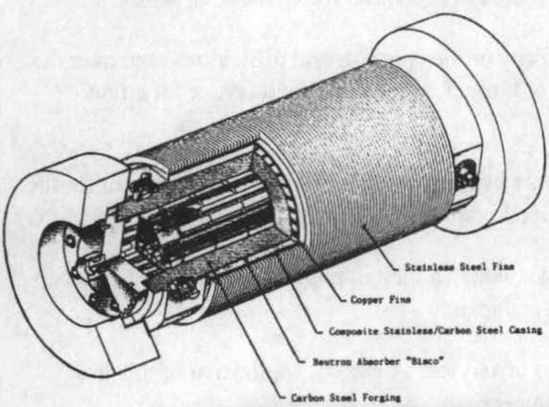
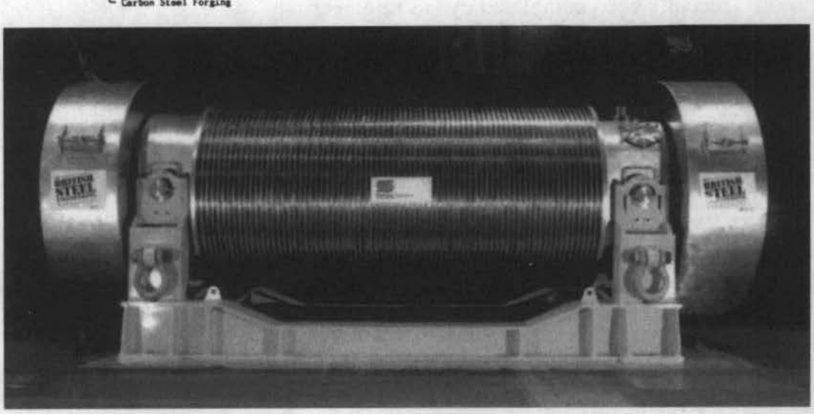


Fig 6 TEPCO Spent Fuel Transport Flask



Since the mixing, pouring and curing procedures for each of these materials was significantly different new, costly, procedures and equipment had to be developed to overcome the production methodologies. Possibly the greatest cost in this area, was the development of procedures to ensure homogeneity of mix and consistency, and batch sampling throughout production. Once cured it is extremely difficult to check the consistency in situ as recognised methods of NDE do not produce meaningful results. The only true way of measuring a neutron shielding materials effectiveness is to perform a scintillation test once the flask is completed. Any problems found at this final testing stage would carry rectification costs of a magnitude to rival the normal manufacturing costs of a flask. Thus any potential flask manufacturer needs to be sure of a capability in their processes before tendering to supply.

Heat dissipation from a dry, storage or transport flask has become a major development over recent years as higher burn up fuels with shorter pond cooling times, and high level vitrified wastes with heat outputs of up to 56 GWd/tU, are used. This requirement for dissipation not only is in place to protect the outside environment, but is a primary consideration with regard to fuel degradation when placed into long term storage, if options for alternative future processing and safe handling are to be maintained.

To increase thermal output fins are attached to the flask body, most usually by welding. This methodology however, generally only accounts for a 15 - 25% surface coverage dependent upon the fin material deployed. To further compound the problem of heat dissipation the neutron shielding added acts as an insulator, so extremely good conductivity from the fins is required. This has meant that materials such as copper are being more widely used. Unfortunately, as with the neutron shielding new materials mean new process development and new capital expenditure for the manufacturers. When it is considered that a flask such as the NFT range, noted previously, has in excess of 7Km of weld applied to it, it can be readily seen that material changes can have a significant financial implication. This cost increase can be compounded by the inclusion of welds in areas of restricted access, requiring sophisticated, electronically controlled bespoke capital equipment to execute. An alternative to this process route is for the attachment of fins by simple mechanical means. In this way a greater flask body surface area can be covered, with cooling efficiency being readily gained once a passive equilibrium has been achieved. From a manufacturing perspective this methodology is much simpler.

Whichever methodology is used, clever adaptation of pre-formed sections can allow self contained units into which the neutron shielding can be poured. This has a clear dual saving in reduced execution and inspection costs, while at the same time the ability to more readily recover from a problem situation by removing the offending segment is enhanced. The solution to any particular application has eventually to satisfy the stringent requirements of the competent authorities, sometimes in more than one country. Again , the efficiency of the implementation of the designers requirements is proven only by the final heat dissipation test on the flask, by which time a rectification routine would carry huge costs and delays.

Primary Gamma Shielding is most often achieved with the use of forged or cast material. Whilst this paper does not propose to comment on the appropriateness of material selection it will as has already been mentioned comment upon the configuration of such pieces either cylindrical or cuboid. By whatever route, a body which is relatively "close to finished shape" can be achieved, thereby reducing manufacturing costs. Cylindrical flasks are both easier to forge, and do not require the level of material removal from the cavity as in a cuboid flask which is more expensive to forge. Cylindrical flasks also offer several advantages in manufacturing as turning operations are generally easier to carryout than the equivalent removal of material from cuboid shapes. The attachment of weld overlay on cylindrical pieces is also less complex as the piece can be turned with the weld head remaining stationary. This assists the manufacturer in the utilisation of modern automatic weld strip cladding techniques. In any of the above cases the capabilities of the proposed materials suppliers and manufacturers requires careful consideration since relatively trivial adjustments to the detail of a design can significantly reduce the eventual production cost and reduce the attendant lead time. The requirement for multiple wall thickness flasks for varying fuel loadings is worthy of review since in all cases the basis of structural design will need revalidation. Where possible additional gamma shielding should be incorporated into a secondary or third level barrier. This method will alleviate the need for changes to the basic primary shielding and therefore the development of new procedures for material production or manufacture.

CONCLUSION

Flask design and manufacture is no different to any other systematic product development consideration. Clear guidelines are laid down by the IAEA to which designers must adhere and competent Authorities enforce. The basis of design is simple, to protect the environment from the enclosed hazard and to protect the hazard from degradation. Whilst the characteristics of the hazard will change the basis of containment design appears to have almost stabilised, as can be seen from the earlier historic review. Barring the introduction of novel materials which may have a dramatic effect on the manufacturing route and licensing of a flask, stability in basic production is expected for some time. This scenario lends itself to the development of "families" of flasks which is being pursued by designs in today's marketplace. Tailoring of each flasks characteristics to meet customers needs will of course require subtle design modification.

If this is to be the case then the manufacturing process and material selection will prove critical in producing commercially acceptable results. It is therefore essential that long term supply relationships are developed between Customerss, designers, competent manufacturers and perhaps even the relevant competent Authority to facilitate a collaborative approach at an early stage to enable a cost effective, safe end product to be supplied within the time scale demanded by the project.