PWR2 AT DOUNREAY

TRANSPORT TO SITE OPERATION

BY

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Foreword

The Royal Navy's new Pressurized Water Reactor—known as PWR2—is the first all-British design for military use. PWR1, which forms the reactor unit for the present fleet of Polaris submarines and nuclear hunter killer types, was based on an American Westinghouse design. PWR2—STF (Shore Test Facility) is the prototype reactor and test facility, at present under construction at Dounreay, which will be used to prove the new design.

The prototype reactor assembly has been designed by Rolls-Royce and Associates (RR&A) and Vickers Shipbuilding and Engineering Limited (VSEL) in line with the usual division of design responsibilities for nuclear submarine machinery. RR&A have in this instance been appointed as the main contractor in view of their role as operators and maintainers of the prototype installation on completion.

This article describes the transportation methods used to transport the partially assembled machinery units from the Shipyard in Barrow-in-Furness, Cumbria, where it has been manufactured and erected by VSEL, to the Naval Reactor Test Establishment, Dounreay, Caithness, Scotland.

Introduction

In January 1976 Rolls-Royce and Associates of Derby placed a preliminary order with Vickers Shipbuilding and Engineering Ltd., Barrow-in-Furness, for the design of the structure necessary to contain the PWR2 prototype for installation at Dounreay. Clearly the design needed to take into account the method and process of construction. The first prototype submarine reactor at Dounreay (DS/MP) was built in the early 1960s by a 'build on site' method: that is all steelwork, equipment and components were shipped as individual units and assembled at site.

The VSEL Management were convinced that a more cost-effective build procedure should be possible, and hence initiated internal studies aimed at investigating the possibilities of reducing 'build on site' costs by fabricating and fitting out large units at Barrow and then transporting these units to site. It was considered that this 'build at Barrow' method would reduce the overall costs, providing the saving in site labour costs was greater than the increase in transportation costs. It was also necessary to demonstrate that the adopted procedures would not incur any programme delays nor involve any unacceptable risk to the units in transit. As a result of this first study VSEL forwarded proposals to RR&A and the Ministry of Defence (PE) in 1977. The proposals were considered to be worthy of a more detailed investigation and a study group (VSEL/RR&A/MOD(PE)) was formed. This study group reported in May 1978 that the proposals were feasible but it was not possible to quantify costs. The study group also recommended against any further studies.

The proposals at this stage involved the use of large multi-wheeled trailers for the overland transport at Barrow and Dounreay. The costs could not be quantified because of a lack of knowledge of the extent of the civil engineering work which might be required. On the proposed route there were bridges and roads to strengthen, power cables to divert, etc. At the Barrow end, a VSEL works entrance would need to be demolished, the overhung load would pass very close to the first floor of private dwellings, and there was a strong possibility of damage to foundations.

Early in 1979 VSEL undertook a second internal study as it was still believed within VSEL that the method could be feasible and acceptable. As a result of developing the previous ideas, VSEL concluded that there could be savings of £1M but that further investigation by consultants was required. In 1979, MOD/RR&A approved the funding of a Consulting Study. This study, by W. S. Atkins, indicated that the new proposals were feasible, but with programme penalties. However, in November 1979, just as it seemed that this study was also to be abandoned, W. S. Atkins presented a supplementary report. This drew attention to the possibilities of using developments in air bag technology for moving large loads, which removed the need for wheeled land transport. VSEL were then made more aware of this technology by Smit International (UK) Ltd.

VSEL and Smit (UK) worked together informally on the project, the outcome being a presentation by VSEL to RR&A/MOD in January 1980, which made a conservative forecast of £½M savings and no programme penalties. This was followed in April 1980 by a VSEL report recommending that 'build at Barrow' be adopted, and with a new forecast of £2M saving. MOD/RR&A approved this recommendation in September 1980. In that month VSEL placed a consultancy contract with Smit (UK) for the development of the proposals and, later, a firm order to undertake the movement of the two main units from Barrow to Dounreay. In January 1981, as a result of the development of the initial proposals and a further cost excercise, VSEL reported expected savings of £9M.

During the period September 1980 until the move took place in June 1985 Smit (UK) London, together with their Head Office team from Smit Internationale Transport, Rotterdam, worked together with VSEL, Barrow-in-Furness as a joint team. The proposals were developed and refined, and the structures designed to permit the use of transportation equipment and the expected transportation loads.

The Solution

It is not the intention in this article to relate all the intermediate steps in the development of the transportation methods used. Refinements to the design and changes in the detailed programme continued until almost the final day of delivery of the equipment to site. The studies indicated that the greatest saving in site effort would be achieved if the primary unit, fully assembled together with the control room, could be moved *en bloc*. This enabled a large amount of instrumentation and controls to be fully completed and tested in Barrow.

The secondary units, being by their nature more dispersed, were capable of being assembled as completely fully outfitted units but the degree of possible testing was limited. Even so complete piping systems were erected, then dismantled for transport; and some auxiliary systems were completely flushed through and tested. As shipped the secondary units consisted of five packages:

A secondary machinery raft (partially dismantled for crane lifts)	151 tonnes
Port support building	43 tonnes
Feed pump raft	13 tonnes
Air ejector support structures (2 off)	12 tonnes
Total	219 tonnes

The solutions to the transport problems were different for primary and secondary units and are shown diagrammatically in Fig. 1. The movement stages for the primary unit, weight 1300 tonnes, were:

(*a*) Skidded from VSEL slipway on to a barge (*E3002*).

(*b*) Barge *E3002* floated off the slipway and towed to Morecambe Bay.

(*c*) Barge *E3002* lifted out of the water to become a deck cargo of a large submersible barge (*Giant 2*).

(*d*) *Giant 2* towed from Morecambe Bay to Sandside Bay by tugs, Sandside Bay being just over a mile from the Vulcan Naval Reactor Test Establishment at Dounreay.

(*e*) *Giant 2* beached hard up against the end of another barge (*Smit Barge 1*) which was used as a temporary causeway to the land.

(*f*) Barge *E3002* rolled by means of air bags across *Smit Barge 1*, and then over the prepared land route to a large pit. This pit was excavated and constructed immediately adjacent to the Vulcan site boundary.

(*g*) When in the pit, *E3002* was transferred from air bag support to water skates. The water skates enabled *E3002* to be easily pivotted and exactly pulled in to line with a skidway path.

(*h*) The primary unit skidded off *E3002* across a prepared concrete apron directly to the final position of the unit in the main hall at Vulcan, the operation being a technical repeat of (*a*) above.

The secondary units movements were a little less complex, namely:

(*a*) Lifted by workshop overhead travelling crane to end of workshop and loaded on VSEL self-propelled multi-wheel transporter. This involved some partial dismantling, due to crane loading limitations.

(*b*) Manoeuvred out of workshop on the multi-wheeled trailers to the lifting position for a very large mobile superlift crane.

(*c*) The mobile crane was positioned to enable the secondary units to be lifted directly on to Barge *E1501* lying alongside in the Barrow Dock system. When on *E1501* the components removed to reduce weight were reassembled on the units.

(*d*) Barge *E1501* towed out of the Barrow Dock system to Morecambe Bay.

(*e*) As moves (*c*), (*d*) and (*e*) for Barge *E3002*.

(*f*) Barge *E1501* was rolled over *Smit Barge 1* and across the prepared land route similar to barge *E3002* but not into the pit.

(*g*) Immediately before the pit, via a temporary side access road and 'roro bridge', the secondary units were transported by trailer to within the main hall at Vulcan.

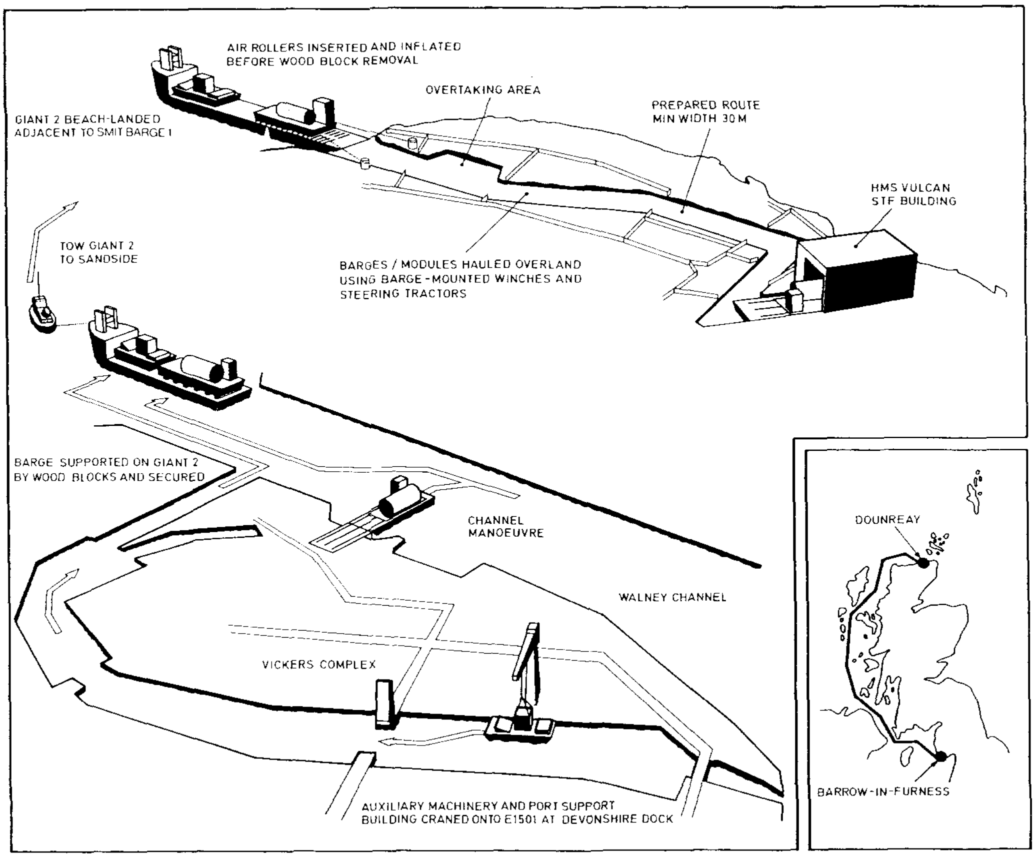

FIG. 1—THE TOTAL MOVEMENT OPERATION

It should be stressed that none of the transportation methods listed above is in any way new development. Skidding equipment, air bags, water skates, and multi-wheeled trailers have all been utilized previously to move structures, ships, etc. The difference with the PWR2—STF operation is one of scale. As far as it is known, no previous operation involved all the methods with such large weights over such distances.

The solution arrived at in 1981 was based upon the equipment available at that time within the heavy tansportation industry. Since then there have been enormous developments in offshore lifting facilities to meet the requirements of the oil industry. With the giant cranes available today, it is probable that a different solution might have been reached.

Primary Load Out

FIG. 2 shows a general view of the slipway area at Barrow-in-Furness immediately before shipment. On the left is the Primary Unit resting in its twelve-framed cradle. The end of the unit is covered with a rubberized fabric as protection against sea spray. In the centre is the horizontal skidway constructed between the build position of the unit and the Barge *E3002*. It consists of concrete blocks, timber packing, steel plates, and the U channel girders of the skidding system. On the right is Barge *E3002* resting on a horizontal cut constructed into the bottom part of the slipway. The tide is out and the bottom of the barge is visible. On the deck of the barge will be seen a steel labyrinth structure and the continuing skidding girders.

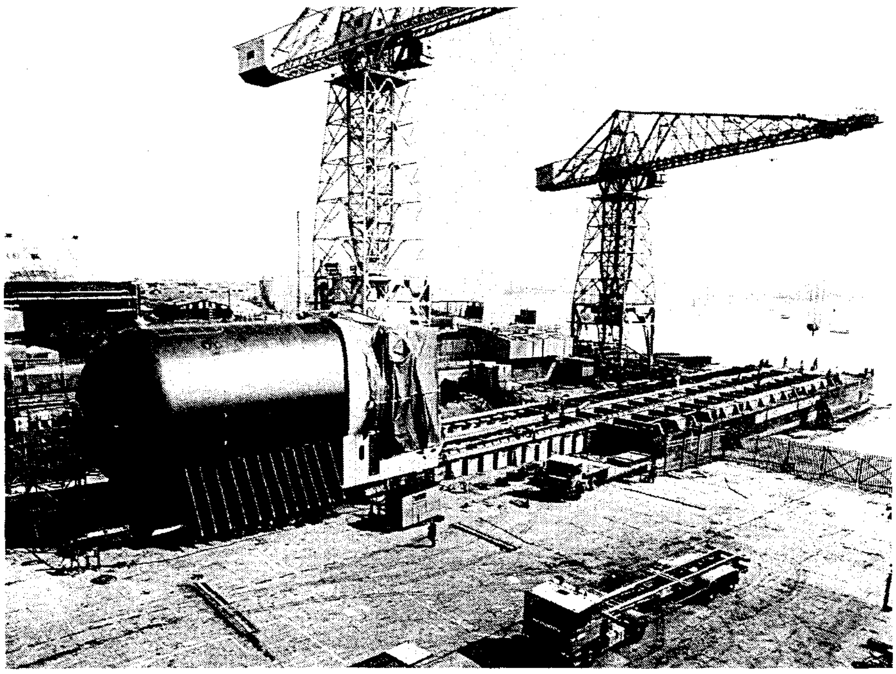

FIG. 2—PRIMARY LOAD OUT AT BARROW

There were several problems in this part of the operation:

(*a*) The construction position on the unit, and the depth of the barge cut had to be a compromise between building the unit out of the tide range, the ability to float-off the loaded barge on a reasonable number of days each month, the stability of the floating barge in transit to Morecambe Bay, and the costs of the berth modifications.

(*b*) The 1300 tonne weight of the unit is not uniformly spread and severe load concentrations occur. The deflections during the skidding were calculated and appropriate allowances made.

(*c*) The deck and basic structure of Barge *E3002* was calculated to be insufficiently strong to allow of the primary unit being moved along its length. The steel labyrinth structure on the deck is deck stiffening added to the barge after arrival in Barrow. This structure was prefabricated in 12 large sections, the height of the sections being deliberately made oversize in order that it could be finally cut to the exact height required to match the construction height of the unit. Internal stiffening was added to the barge structure in Rotterdam before arrival in Barrow.

(*d*) The skidding channel needs to be exactly horizontal and does not allow of any height discontinuities. The overhanging 'swim end' of the barge was therefore supported by pouring concrete to fill the space between the barge and the ground.

(*e*) The starboard building being offset from the centre line of the unit gave an asymetric loading. This was counteracted by placing a series of concrete blocks on the port side of the barge within the labyrinth structure. These also can be seen in FIG. 2.

(*f*) The time available with sufficient height of tide to permit float out and transit down channel was limited. If a first time horizontal float-off was to be achieved it was essential to know the exact weight and position of the centre of gravity of the unit. It was therefore decided to weigh the complete unit. This proved to be less difficult than at first thought, when undertaken by a specialist contractor. Twenty-six hydraulic jacks and load cells were positioned at selected strong points under the primary unit. The arrangement of two of the jacks is shown in FIG. 3. The direct read-out of the weight taken by each jack was

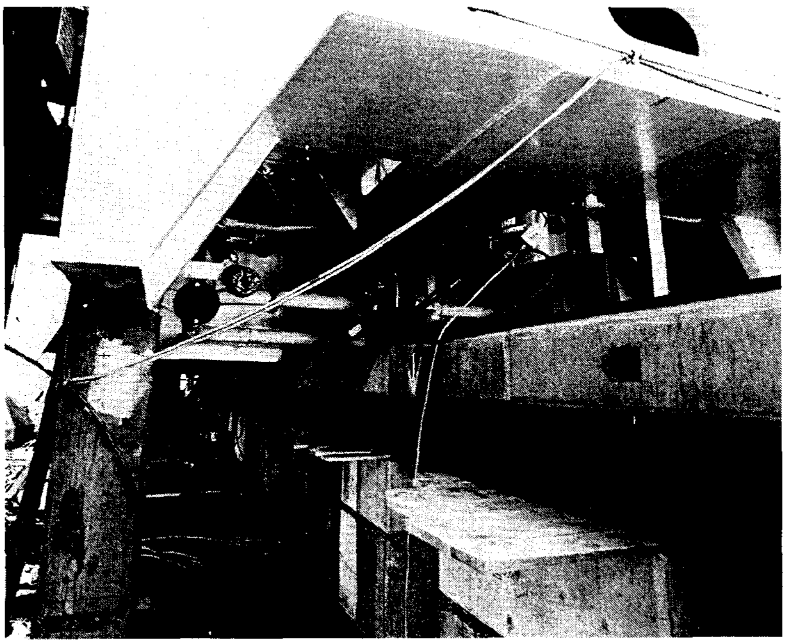

FIG. 3—ARRANGEMENT OF JACKS FOR WEIGHING THE PRIMARY UNIT

shown on a number of digital recorders positioned at the side of the unit. The entire diesel-driven hydraulic pump units, hydraulic controls, and control desk were carried on an articulated lorry. Without any noise at all the unit was lifted approximately 2 cm. The first reading gave a toal of 1269·6 tonnes. The unit was weighed a further three times with load cells switched between jacks to eliminate any possible errors. The total did not vary by more than 1·5 tonnes. Subsequently a careful record was kept of any deletions and additions. On the appointed day, Barge *E3002* floated off exactly horizontal and within five minutes of the predicted time, at the calculated draft.

(*g*) Whilst Barge *E3002* was in the berth cut it was necessary to pump it full of water ballast in order to ensure it did not float on a high tide. The amount of water ballast could of course be reduced once the primary unit was loaded on the barge. The final deballasting had however to take place between the last high tide before float off and the required float off tide. This was achieved with portable electric and air driven pumps.

(*h*) Fears were expressed that as the time of high tide did not coincide with slack water in Walney Channel—there being a 2–3 knot tide at high water—Barge *E3002* would be damaged by striking the guide posts each side of the berth cut. Two of these guide posts can be seen in FIG. 2. Visual examination of water movement close to the slip at high water gave indications of a reverse swirl motion. In the event the tugs removed Barge *E3002* from the berth cut without making any contact with the guide posts.

The skidding equipment is essentially very simple and is shown diagrammatically in FIG. 4. The skid channel rests on the prepared skidway or deck of the barge. In the bottom of the channel is a series of PTFE pads. Resting on and able to slide upon these pads are very stiff box beams. The box beams, about 4·5 metres long × 0·5 m × 0·35 m, are linked together to give a degree of flexibility and pass completely below the unit to be lifted. Resting on top of the skidding box beams are a number of hydraulic jacks. Only one jack is shown in FIG. 4.

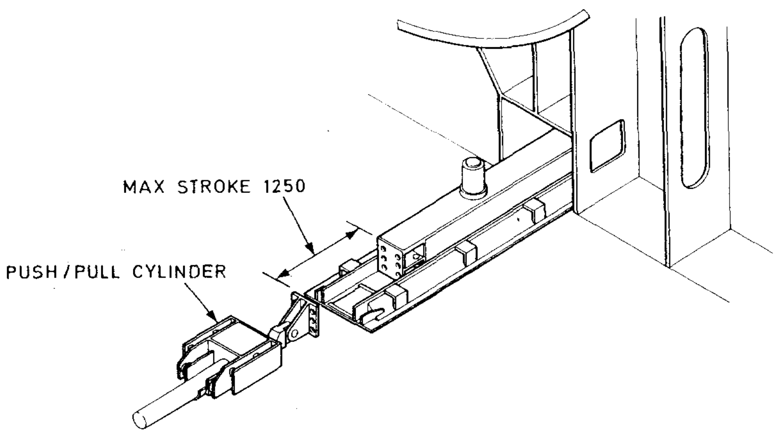

FIG. 4—OVERALL ARRANGEMENT OF SKID UNIT

For the primary unit 26 jacks were employed, 24 under the primary containment and 2 under the starboard support building. As will be seen from FIG. 4 the primary cradle structure was designed with a box cut out for the skidding equipment. The jacks were positioned on the skidding beam to be directly under the cradle frames and hence strong points of the unit.

To skid the box beam over the PTFE pads there was a hydraulic push/pull cylinder at each end of the skidway path. This cylinder could be locked to the right-angle protections along the side of the skidway channel.

The skidding operation therefore was to first jack up the whole primary unit by about 75 mm. The 26 jacks were arranged in three separate groups, and a floating condition maintained in each group, thus allowing a three point support system. This hydraulic system was separate from the hydraulic skidding system. Applying pressure to the skidding push/pull cylinders moved the whole unit just over one metre. On unlocking the cylinders from the channel and reversing the hydraulic supply to the push/pull cylinders, the unit remained at rest and the cylinder closed up on itself. Relocking the cylinder to the beam enabled the operation to be repeated. Thus the primary unit moved along the structure in a series of one metre steps.

Secondary Load Out

The Secondary Load Out was very much a conventional multi-wheeled bogie and crane affair, only made difficult by crane weight limitations and a height level difference between the assembly shop and the dockside. This was largely solved by the use of a mobile superlift crane. This crane lifted a load of 100 tonnes on an arc of 37 metres radius, transferring in one movement from just outside the door of the Assembly Shop to the deck of Barge *E1501*. This large mobile crane was on site in Barrow for only four days. During this time it was assembled, tested with a test load, employed lifting the five units into place, and dismantled for departure by road.

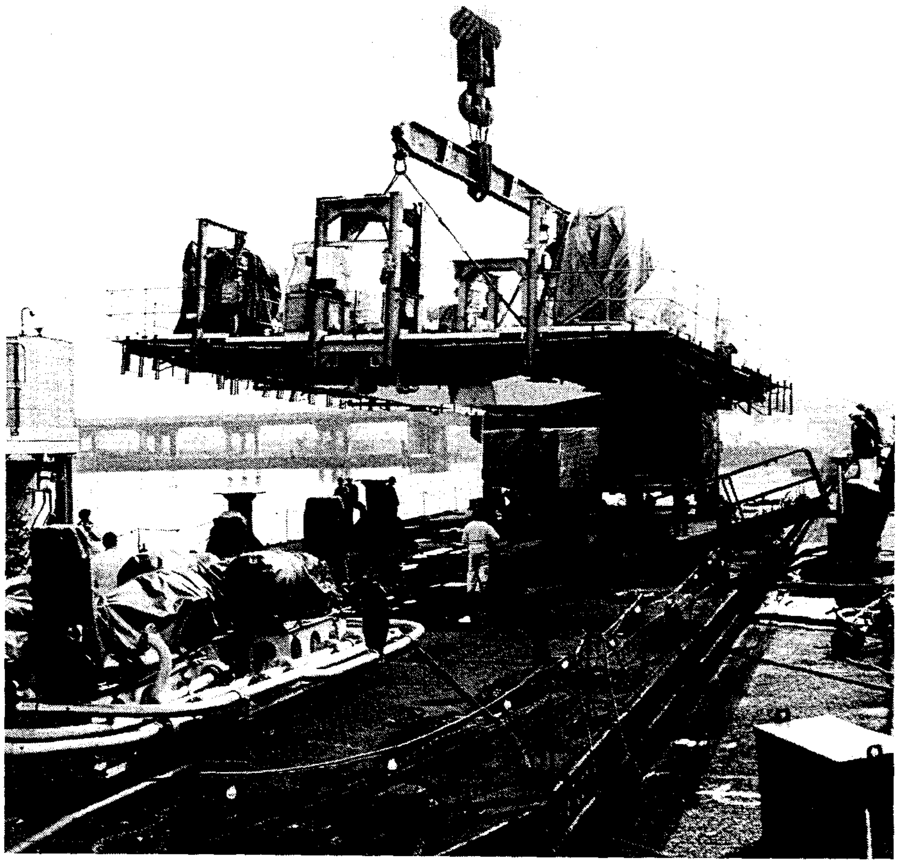

FIG. 5—SECONDARY UNITS BEING LOADED ON BARGE 'E1501'

FIG. 5 shows a view of the deck of Barge *E1501* whilst being loaded in the Barrow Docks. The secondary raft, in a stripped down condition, is on the point of being placed on the four support stools. In the left foreground is the main feed pump raft complete with four feed pumps and piping. Immediately behind the pumps is the end of one of the air ejector/condenser structures with piping visible. On the right end of the barge is the partially hidden Port Support Building on stools and covered by protective rubberized fabric.

Loading in Morecambe Bay

The approach employed here was to find a geographical loading position where the stern of *Giant 2* could be placed on the sea bed, and with sufficient depth of water at high tide for the deck cargo to be floated into position over the main deck. The main deck becomes completely submerged and only the bows remain above water.

Four suitable geographical positions were identified in Morecambe Bay. The position finally selected was Lightning Knoll some 3 miles south-west of the southern tip of Walney Island. The weather was ideal for the operation with no wind or swell, but a strong tide set across the deck of *Giant 2* made the final positioning of Barges *E3002* and *E1501* difficult.

Giant 2 is really a floating pontoon with the following dimensions:

length overall	140·00 m
width	36·00 m
depth	8·50 m
draft unballasted	1·80 m
draft to load line	6·66 m
deck load capacity	24 000 tonnes
deck strength	15 t/m^2

The hull is divided into 28 ballast compartments. These can be flooded from the sea or deballasted by means of compressed air. The small machinery space in the bow contains only air compressors, electrical generators, and hydraulic power packs. The bridge structure is in fact the control room.

The procedure for the lifting operation is for *Giant 2*, with her stern on the sea bed, to wait for the tide to fall, when the load then settles on to the deck. When the deck load is in place, the stern of the barge is brought off the sea bed by deballasting. This procedure avoids transient stability problems.

After *Giant 2* has been fully loaded the barges have to be secured in order to prevent any movement during the sea passage. The sea fastenings consist of short lengths of girders which touch the side of the barges and are welded to the deck. No attempt is made to impose any vertical constraint to the barges or directly secure them to the deck.

Sea Passage

The sea passage around Scotland was uneventful, apart from meeting a Force 8 gale while proceeding through the Minches. The passage speed was 9 knots and the towing tug was *S.L. 114*, one of the large North Sea Supply Vessels owned by Smit Lloyd.

Off Loading at Sandside Bay

During the last six months before completion of the PWR2—STF units at Barrow, work had been in progress at Sandside Bay making preparations for the off loading. A horizontal shelf was cut into the rocks of the east side of the bay. This shelf was excavated at low tide and then covered with a layer of 40 000 sandbags. On a suitable high tide the barge *Smit Barge 1* was floated into position and ballasted down on to the sandbags. *Smit Barge 1* contains a machinery space complete with diesel-driven pumping equipment and is able to ballast and deballast as required. Incidentally *Smit Barge 1* was only launched on the 20th March 1985 and this was its first operation. The gap between the end of *Smit Barge 1* and the sand dunes was filled with material excavated from the land route to form a causeway.

FIG. 6 shows *Giant 2* being floated into position astern of *Smit Barge 1* and about 2 metres from its final position. This berthing operation was achieved using small harbour tugs and also winches on board *Smit Barge 1* pulling on wires attached to bollards on *Giant 2*. The operation was carried out extremely smoothly with *Giant 2* gradually being eased into position as the water depth permitted.

When beached, *Giant 2* was entirely resting on sand. The problem here was that the natural slope of the beach would tend to cause *Giant 2* to have a slight list to starboard. This was not acceptable for off loading barges *E3002* and *E1501*, and so a shallow shelf had to be cut in the sand by bulldozers at low tide to form a beaching area. This shelf was not horizontal but inclinded to match the natural beach slope and the gradient of the land route. Unfortunately each high tide disturbed this sand preparation and for the last few low tides before beaching corrections had to be undertaken.

FIG. 6—'GIANT 2' AND 'SMITBARGE 1' IN SANDSIDE BAY, DOUNREAY

The precision of this civil engineering work is best illustrated by the fact that in the very last low tide it was decided that 10 cm more of sand had to be removed from the whole beaching area. A bulldozer effected this during the low tide time available, working in 2 to 3 feet of water. Mounted on shore was a lazer beam transmitter giving out a datum level. In the bulldozer driver's cab was a receiver which simply indicated a position above or below the datum; hency by driving to the indicator the necessary level bed was produced and the 10 cm of sand removed.

One phenomenon observed during the time that *Giant 2* was beached astern of *Smit Barge 1*, was that their relative deck heights varied as the heights of the high tides changed. *Smit Barge 1* was firmly ballasted down on to sandbags and rock and could not move. *Giant 2* was ballasted down on to the sand bottom of the beach, and it would appear that as the head of water over the sand increased the sand expanded and lifted *Giant 2*. A maximum rise of 10 cm was noted with the highest experienced tide. This phenomenon is still being investigated.

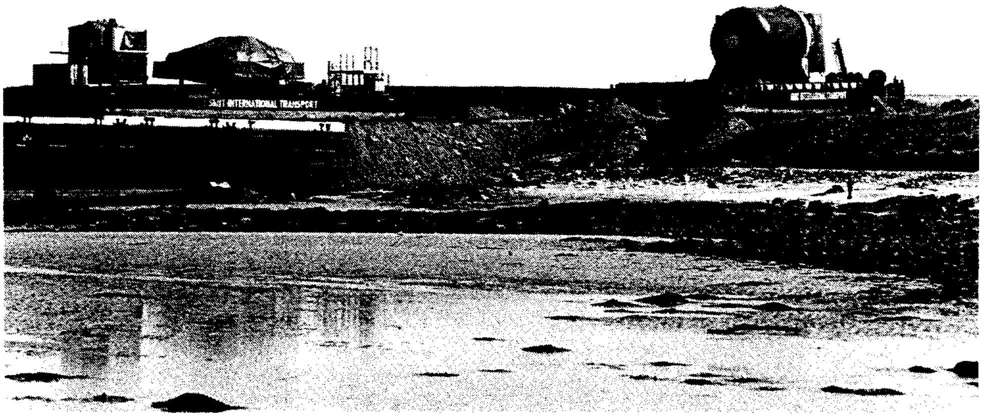

FIG. 7—BARGES 'E3002' AND 'E1501' AT START OF ROUTE ASHORE

In FIG. 7, *E3002* is fully ashore over the causeway and on the land route, while *E1501* is parked half on *Smit Barge 1* and half on the shore. The deck of *Smit Barge 1* had been covered with approximately one metre depth of sand in order to bring the top of the causeway level with the deck of *Giant 2* and to form a smooth transition to match the contour of the land route.

Air Bag Rolling

As stated earlier the one technique which made the whole operation economically possible was the use of air bags for transporting heavy loads over relatively unprepared ground. The general arrangement is shown in FIG. 8 where *E3002* with a total all-up weight of 2360 tonnes is supported on approximately 90 air bags, 45 on each side of the barge. Each air bag is nominally 0·6 metre in diameter and 9 metres long. The working pressure in the bags was designed to be 0·45 bar. The system is self-correcting.

It is convenient to consider each bag is acting like an individual caterpillar track and mounting any obstructions. If due to inaccuracies in the roadway the load is not evenly distributed on all bags, then pressure in the more heavily loaded bags increases to match the load. This uneven loading occurs

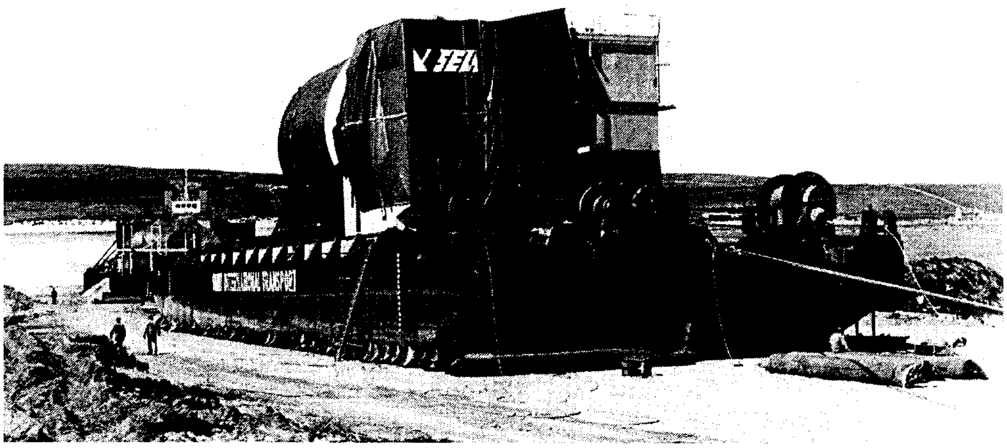

FIG. 8—'E3002' ON AIR BAGS

for example when going over a hill or bridging a ground depression. The bags used are made of a heavily reinforced rubber and are water pressure tested to 2·5 bar.

In the figure, *E3002* is temporarily at rest and is held by a stopper wire from the front centre of the barge to a ground anchor point. This was necessary when changing the position of the hauling wires. Barge *E3002* hauled itself over the ground by means of two diesel-driven hydraulic traction winch units mounted on the front of the barge. The winches can be seen in the front centre of the barge with the cable drums and fairleads on each bow. Each cable was led from the fairlead to a pulley attached to the ground anchor, back to a pulley mounted on the barge front, and then back again to the ground anchor pulley and finally secured back to the barge. With this 4 part fall arrangement approximately 160 tonnes pulling force could be obtained on each wire. This maximum arrangement was varied as the slope of the haul road changed.

Barge *E1501* being much smaller, its total weight of 514 tonnes could be easily moved by two bulldozers connected to the ground anchors via single sheaves or direct depending on the slope. The number of air bags used for *E1501* was not critical but it averaged about 48.

As can be seen the air bags are fed under the front of the barge by hand utilizing a specially constructed feed-in ramp attached to the bow. These wooden ramps and steel frames were added to *E3002*, front and rear, after the barges were embarked on *Giant 2* in Morecambe Bay. Each barge also carries two diesel-driven air compressors which enable the air bags to be inflated or topped up as required anywhere along the route. The air connection valve is bonded to the square end of each bag.

The first two and a half days of the air bag rolling of *E3002* turned out to be the most difficult and trying of the whole transport operation. The air bags refused to roll evenly and twisted like two links in a sausage, the twisted portion showing two or three differential turns between the ends of the bag. This gave great confidence in the strength of the bags, in that none burst, but bags were twisting after a relatively short travel distance. They had constantly to be examined from the side and, when twisting occurred, the operation stopped. Twisted bags were then deflated, removed, untwisted, reinserted under, and reinflated. This was extremely hard manual work and was time-consuming. The barge was also being turned as it moved along, thus complicating the problem, a slight change of direction being obtained by feeding in the air bags at a slight angle and pulling more heavily in the required direction. The solution to the twisting problem was found when the pressure in the air bags were increased to between 0·6 and 0·7 bar. After this, progress was extremely good with, at times, the rate of movement only limited by how fast the two tractors could pull the bags coming out of the back round to be reinserted at the front. Going downhill, the hauling wires were led astern of the barges to act as preventers.

Land Route

The air bag rolling requirements for the land route were minimal, namely no sharp stones and no cross fall. Selecting the best route was the subject of several investigations before that shown in Fig. 9 was chosen. The distance is just over a mile and is the shortest route, but it had the disadvantage of needing to cross the brow of a hill, the slope to be negotiated being 5·5%. The land was agricultural fields and grass. The route preparation was limited to removing the top soil to the side, as can be seen in Fig. 8, and spreading a thin layer of quarry sand to fill any holes and correct any cross fall.

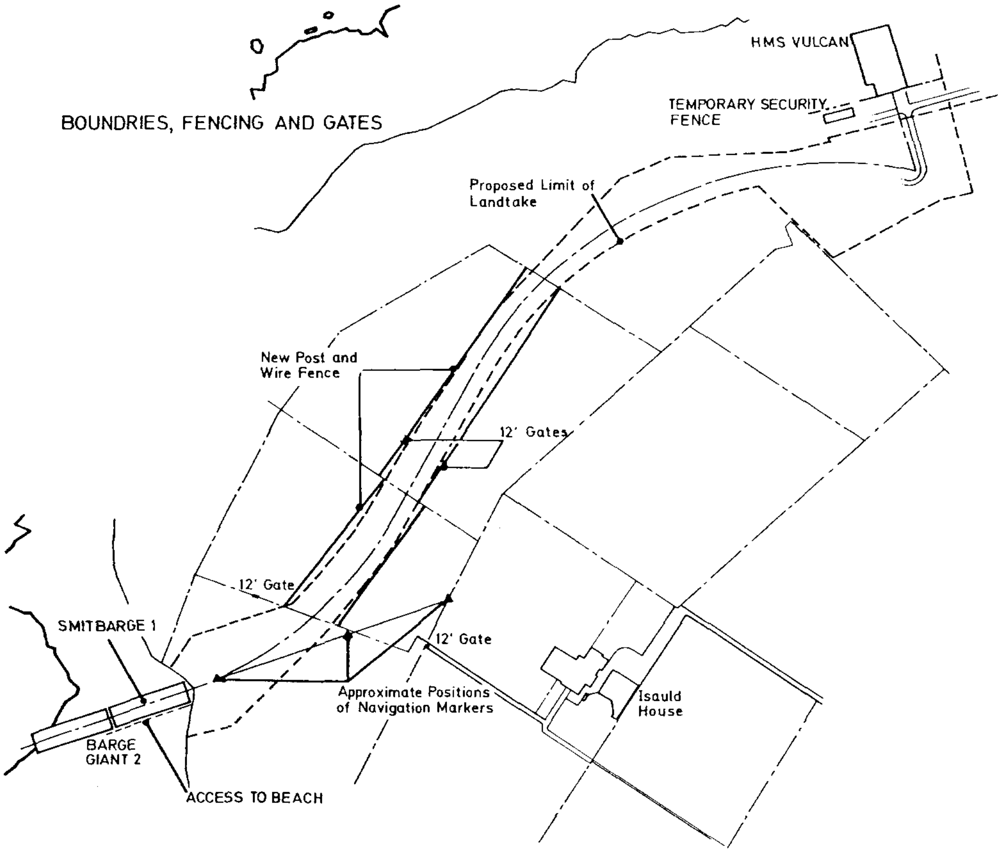

FIG. 9—THE LAND ROUTE AT DOUNREAY

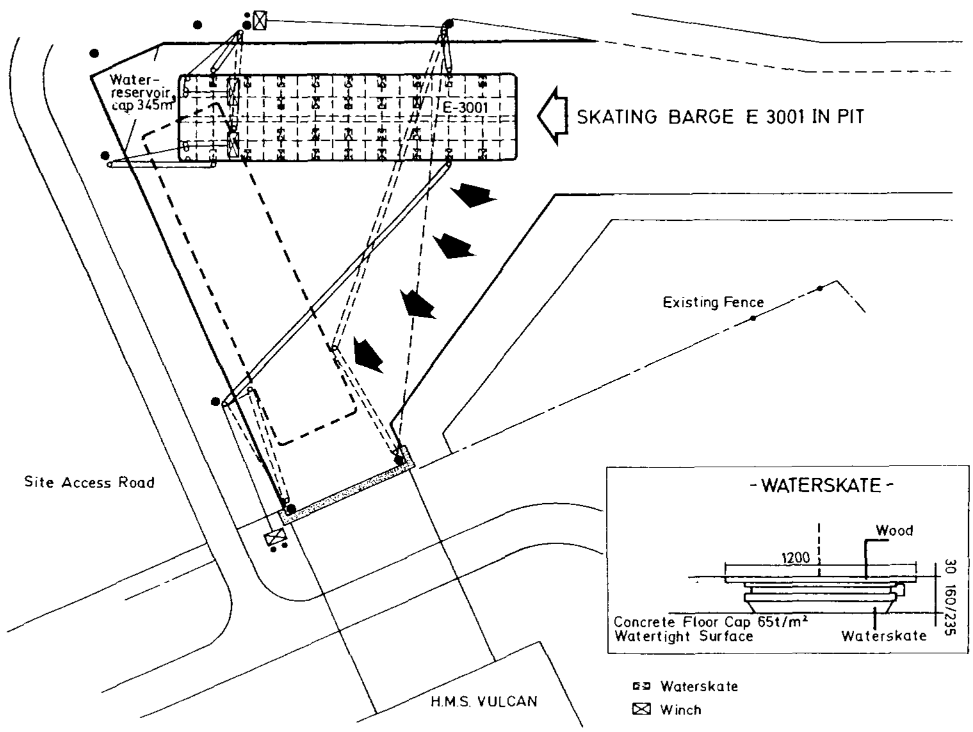

FIG. 10—THE PIT AND DIAGRAM OF WATER SKATE

Spaced along the route were pairs of ground anchors to be used for hauling the barges. The design of these anchors was most interesting. Each top anchor block was held into the bed rock by 3 sets of wire cables (12–15 wires per set) grouted into holes drilled up to 15 metres deep. The 3 sets of wires passed through the top block and were secured to an inset in the block by means of a metal collet. Using a hydraulic operated attachment, the wires were placed under tension then secured by the collets. Thus the top anchor block was firmly held against the bed rock. An initial prototype anchor was fully tested *in situ* to prove the method and ground conditions. The bed rock was about 1 metre below the top soil.

At the Vulcan end of the land route it was necessary to excavate a large triangular pit as shown diagrammatically in FIG. 10 and pictured in FIG. 11.

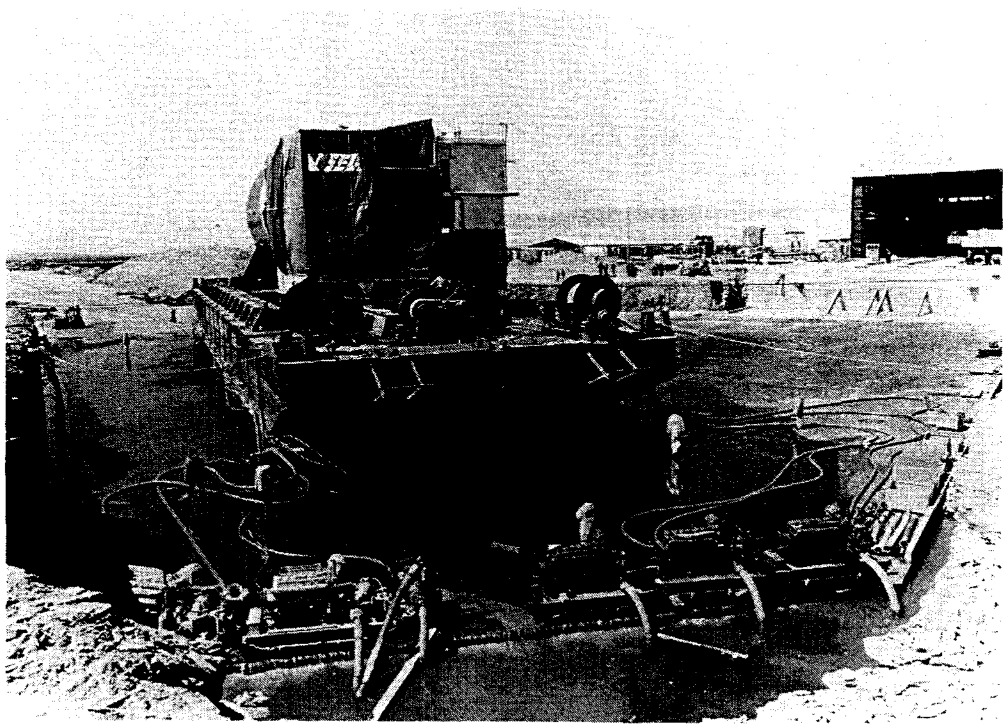

FIG. 11—'E3002' ON WATER SKATES IN PIT

The primary object of the pit was to lower *E3002* into the ground so that the base of the primary unit cradle was at the same height as the floor of the main building in Vulcan used to house the PWR2—STF. A secondary object was to pivot the entire barge through about 70° to line up with the entrance through the end of the main building. This pivoting action reduced the length of the haul road and saved considerable excavation costs. Tight turns are not possible on air bags and the land contours prevented a wide sweeping approach. The size of the pit is illustrated by the fact that 85 000 tonnes of rock were excavated, and 6500 square metres of reinforced concrete laid to form a level base. This reinforced base was needed in the pit to permit the movement of barge *E3002* on water skates.

Water Skates

After *E3002* had been rolled into the pit on the air bags, the bags were systematically replaced by lines of water skates. Water skates operate on exactly the same principle as hovercraft, only using water instead of air. The inset in FIG. 10 shows the arrangement of a water skate. Approximately $1{\cdot}20\ m \times 2{\cdot}40\ m \times 0{\cdot}20\ m$, each unit is built of plywood, has a shallow plenum chamber, and a rubber skirt on the bottom face. Supplied with water at a pressure of 6 bar, each unit will lift up to 100 tonnes. For *E3002*, 28 water skate units were employed in a 7×4 matrix arrangement. The water skates are of sufficient strength to support the total load when not pressurized.

FIG. 11 shows *E3002* in the course of being pivotted and moved across the pit. In the foreground are the portable diesel-driven pumps supplying the water skates via flexible hoses and an arrangement of manifolds. The leakage from the skates is remarkably small, and does of course depend upon the surface finish of the ground. For small jobs it is only usually necessary to spread sheets of polythene. This has the advantage of protecting the rubber seal of the unit. This was not practical for PWR2—STF so instead the whole concrete floor of the pit was dressed to remove small irregularities and given two coats of bitumastic paint. A slight fall on the pit floor directed leakage water back to a reservoir in the corner of the pit.

With all the skates pressurized, *E3002* could be moved in any direction almost effortlessly by means of four small winches and blocks and tackles arranged around the pit. The final motion was to pull the end of the barge hard up against a concrete apron built out from the main building to the edge of the pit. The main building with the bottom half of the end removed to permit the entry of the PWR2—STF units can be seen on the right of FIG. 11. Also in this picture can be seen the four steel girders let into the vertical face of the apron and used to support the overhanging swim end of the barge during the off loading procedure.

Primary Load In

The loading in of the Primary Unit to its final position within the main building of Vulcan was a repeat of the load out procedure used in Barrow, employing skidways and PTFE blocks. The channels and equipment were brought by road from Barrow and assembled before *E3002* arrived at site. The use of the water skates permitted very accurate positioning of *E3002* in relation to the main building. No difficulties were experienced with the skidding operation and the main unit was subsequently placed to within 2 mm of the designated position in the main building.

One of the problems here was that the floor of the building had already been constructed and it included a large duct to house the main sea water condensers. This duct had therefore to be filled with concrete blocks, cast *in situ*, of sufficient strength to support the transit of the primary unit.

Secondary Load In

The method employed for off loading the Secondary Units from Barge *E1501* to within the main building is illustrated in FIG. 12. Immediately before the pit, on the excavated approach slope down, a sideways off-loading position was constructed. By means of a number of steel beams pivoting in housings on the side of the barge, a roro bridge was created flush with the deck. At the selected position the roro bridge was horizontal and rested upon a temporary access road constructed so as to make a side approach to the Vulcan main hall. A multi-wheeled trailer with built-in hydraulic lifting jacks then crossed the roro bridge and was positioned under the secondary machinery raft. This was the reason for the height of the four support stools shown in FIG. 5. The trailer then transported the machinery raft to inside the main hall for lifting by the overhead travelling crane. With the secondary machinery raft removed from the deck of *E1501*, sufficient space was available to repeat this off-loading procedure for the Port Support Building.

To off-load the main feed pump assembly and the air ejector support structures a mobile crane was driven over the roro bridge on to the barge. From here a mobile crane lifted these three smaller units directly on to the multi-wheeled transporter which remained on the side approach road. They could then be taken directly into the main hall.

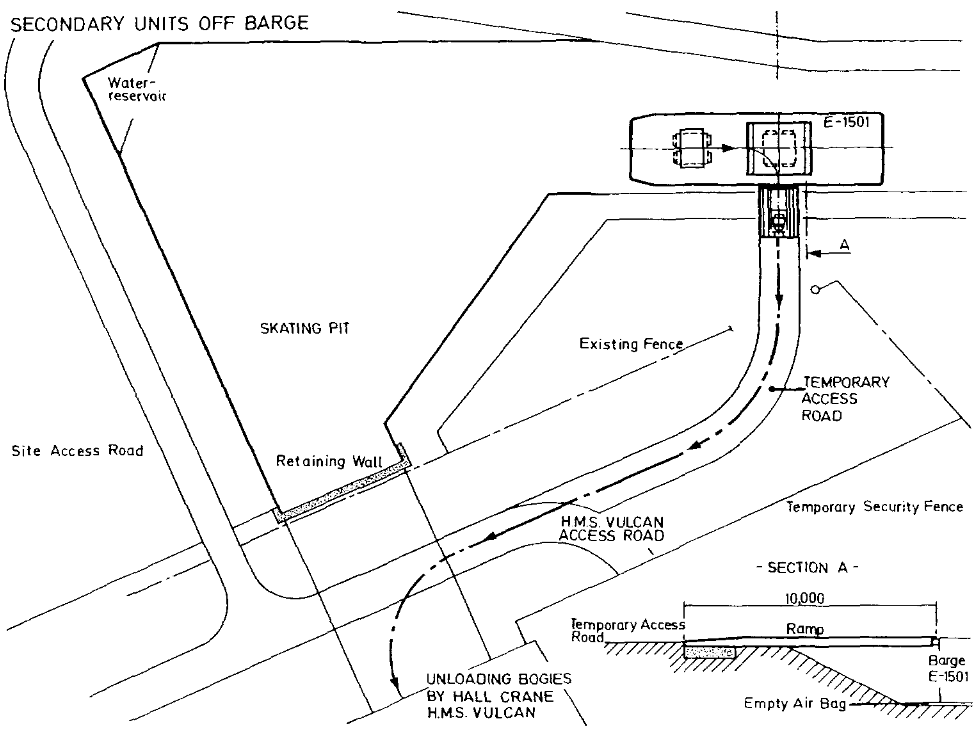

FIG. 12—SECONDARY LOAD IN

Return Route

With all the loads safely delivered it was only necessary to return the empty barges overland back to *Giant 2* by the same methods, i.e. water skates and air bags. With the reduced weight and previous experience, and not such a steep slope to climb in the return direction, speed records were broken. Barge *E1501* did the entire trip from pit entrance to *Giant 2* in $7\frac{1}{2}$ hours, including the lunch break.

In order to achieve a better load distribution on *Giant 2*, and hence an easier float off, *E3002* was loaded before *E1501*. This entailed building a passing place on the route for the barges to pass each other. The overland return of the barges, the unbeaching of *Giant 2*, followed later by the unbeaching of *Smit Barge 1*, took place without incident.

One of the conditions imposed on the operation when planning permission was obtained was that the land route and beach area would be restored, as far as was possible, to its original state. As soon as the barges passed on the return journey this operation was commenced by the civil contractor and was completed in about two months, all fences, walls and topsoil being replaced before handing back the land to the tenant farmer.

Programme and Planning

The programme as planned for the whole operation envisaged that, from float off of Barge *E3002* at Barrow, it would take 23 days to place the primary unit in its final position, and 26 days to deliver the secondary units to within the main hall. In practice the times taken were 16 days and 19 days. The majority of the credit for the success of this operation must go to Smit Internationale Transport of Rotterdam who were in complete charge throughout the operation.

Such success is not however obtained without considerable detailed planning. For example there were five volumes of Operation Manuals which detailed every aspect of each part of the operation. They included the personnel responsibilities, equipment required and arrangement, precautions, necessary inspections, and fall-back arrangements. There was in addition a volume of calculations in which the strength/power/displacement, etc. of every unit was calculated and checked.

It was also necessary during the planning stages to demonstrate to the MOD(PE) that the risks in undertaking such a transport operation were minimal, in view of the importance of the loads being transported. To this end several duties were undertaken, some being subcontracted to organizations such as W.S. Atkins, Lloyds Register of Shipping, and the National Maritime Institute. More effort was expended on such safety studies than on any other aspect of the operation. Even so, not everybody in Barrow and Bath was fully convinced.

The marine operations of loading in Morecambe Bay and off-loading in Sandside Bay were of course very weather-dependent. The operation manuals laid down the weather and sea conditions that had to prevail, together with the requirements for the following 72 hours forecast, before the start of any operation. The week before the start of the whole operation a daily management meeting was held to confirm the immediate preparation programme. To assist at this meeting the London Weather Centre was subcontracted to supply twice daily a detailed forecast covering the following 4 or 5 days throughout the operation. A representative from the London Weather Centre was installed in a portakabin on the slipway at Barrow, together with all his data-receiving equipment, and a very satisfactory flow of information resulted.

Studies had been undertaken into the historical weather statistics of both Morecambe Bay and Sandside Bay before deciding the timing of the operation. In the event the weather at Morecambe Bay was ideal, while at Sandside Bay only one day of the programme was lost due to weather. It was necessary to delay the beaching of *Giant 2* for 24 hours to allow the sea swell in the bay to decrease, *Giant 2* and the towing tug *SL114* waiting off the coast meanwhile.

The team effort and spirit prevailing throughout the operation was incredible to observe, especially when the variety of origin of the subcontracting teams is known. The following organizations were involved:

Smit (UK) Ltd., London	Main contractor
Smit Internationale Transport BV., Rotterdam	Project management, operational control, and large barges
Jasto BV., Breda, Holland	Transport consultants
Harms Bergung GmbH, Hamburg	Air bag rolling
Smit Lloyd BV., Rotterdam	Tugs
Alexander Towing Co., Liverpool	Tugs
Gerrit J. Eerland BV., Rotterdam	Barges
Holyhead Boatyard Ltd., Holyhead	Offshore seafastenings
Van Seumeren BV., Utrecht	Heavy land transport
Hewden Stuart, Castleford	Heavy lift mobile crane
Sunters Bros. Ltd., Northallerton	Transport bogies

Lifting Services International Ltd., London	Waterskating
John Gibson Lifting Agency Ltd., Middlesbrough	Weighing
London Weather Centre, London	Weather forecasting
Jamieson MacKay & Partners, Glasgow	Civil consultants
Morrison Construction Ltd., Inverness	Civil contractor
Vickers Shipbuilding and Engineering Ltd., Barrow-in-Furness	Loading and unloading arrangements, Barrow and Dounreay.

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Any opinions expressed in the paper are solely the author's and do not necessarily reflect the views of VSEL or the MOD(PE).