N76-15060

# THE TRANSPORT OF NUCLEAR POWER PLANT COMPONENTS

S. J. Keating, Jr.*

ABSTRACT: This paper deals with the problems of transporting nuclear power plant components to landlocked sites where the usual mode of transport by barge cannot be used. Existing methods of ground-based overland transport are discussed and their costs presented. Components are described and traffic density projections made to the year 2000.

Plots of units transported versus distance transported are provided for units booked in 1973 and booked and proposed in 1974. It is shown that, for these cases, overland transport requirements for the industry will be over 5,000,000 ton-miles/year while a projection based on increasing energy demands shows that this figure will increase significantly by the year 2000. The payload size, distances, and costs of existing overland modes are significant enough to consider development of a lighter than air (LTA) mode for transporting NSSS components.

## INTRODUCTION

To meet the ever increasing demand for electric power as economically as possible, the size and number of nuclear fueled units have been increasing over the years. (At present, the AEC has set a maximum size limitation of approximately 1300 megawatts of electrical power per unit, though it is expected that the next step up to 1500 megawatts electric, which will correspond to a core thermal power of 5000 megawatts, will occur around 1979 with plants of this size going into service around 1987.) Many of the units being booked now will be located at landlocked power plant sites. The problems of overland shipment of the large components and subassemblies may place limits on the extent to which the economics of scale and the benefits of shop fabrication can be exploited in the future.

The concern with the future transportation requirements is not unique

*Project Engineer, Combustion Engineering, Inc. Windsor, Connecticut, U.S.A.

to Combustion Engineering, Inc.; it is shared by others in the industry. Though existing means can be used to deliver all units booked or proposed to date, a lighter than air (LTA) airborne mode may offer significant economic advantages for the future.

## PAYLOAD

Specifically, the payload stimulating this consideration of a LTA mode of transport is the nuclear steam supply system (NSSS). NSSS provide energy input to turbines that drive electric power generators. This paper deals with NSSS using light water moderated reactor cores. According to a recent U.S. Atomic Energy Commission projection, light water reactors will continue to make up the bulk of NSSS sold in this country. There are two types of NSSS that fit this category: the pressurized water reactor (PWR) and the boiling water reactor (BWR). The PWR system uses a closed, reactor coolant loop containing water at a typical pressure and temperature of 2250 psia and 621 F to transfer core thermal power via large shell and tube type steam generators to a secondary water loop where boiling occurs at a typical pressure of 1000 psia. The steam generated goes to the turbine, is expanded, condensed, and then returned by the main feedwater pumps to the steam generator. In contrast to the PWR system, the BWR system permits the boiling to occur in the reactor core within the reactor vessel from which saturated steam at a typical pressure of 1000 psi is delivered to the turbine.

Because of the high temperatures and pressures within the vessels, the energy flow they handle, and the very high emphasis on safety and reliability, the vessels are large and heavy. PWR systems may have reactor vessels (Fig. 1) which weigh up to 540 tons, and are 22 feet in diameter and over 40 feet long. The vessel shown in the foreground of

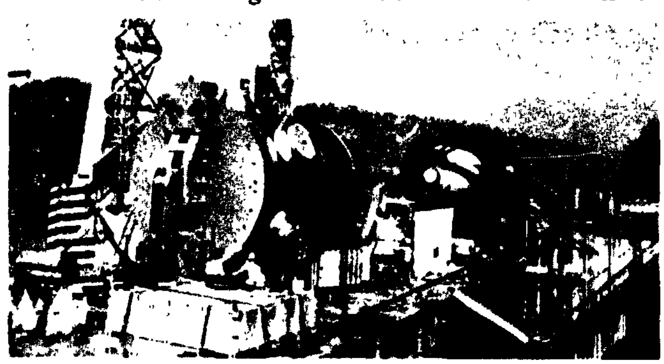


Figure 1: Pressurized water reactor vessel (foreground) and steam generator (background)

Fig. 1 has walls over 8 inches thick. The steam generators (Fig. 2) weigh up to 800 tons, and are up to 21 feet in diameter and up to 65 feet long. From two to four steam generators are used in each NSSS. BWR systems have reactor vessels (Fig. 3) that weigh up to 730 tons, and are up to 2? feet in diameter and up to 62 feet long. Typical weights and sizes for this equipment and the rest of the components for current NSSS and for the next generation NSSS are summarized in Table I.

Other utility equipment is in the same size and weight range. For instance, a typical 1300-Mw generator stator may weigh up to 500 tons and be up to 40 feet long. Heights and widths are presently in keeping with the transport "window" imposed by present land-based modes though this situation may change as power level is increased.

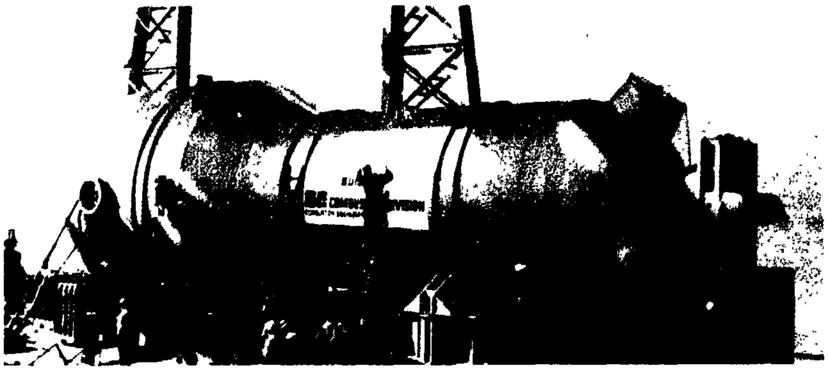
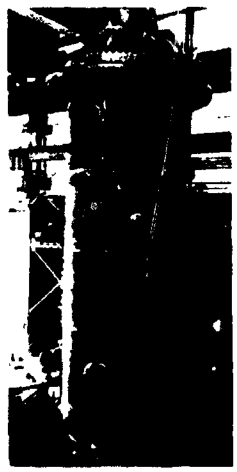


Figure 2: Steam generator for pressurized water reactor

Figure 3: Boiling water reactor vessel assembly



Another item of special interest is the moisture separator/reheater unit which processes steam going from the high pressure turbine to the low pressure turbines. These pressure vessels may weigh up to 150 tons, and are up to 100 feet long and 13 feet in diameter. Though the weight and diameter are within present ground-based transport mode capability, the length presents a serious problem when negotiating curves.

The fabrication of these components requires careful welding and heat treating. Following heat treating, the vessels are subjected to several independent nondestructive tests, including hydrostatic pressure, X-ray, ultrasonic, and magnetic particle tests. Recently, there have been attempts to field fabricate BWR vessels. Indications are, however, that it will be more economical to develop or adapt transportation modes so that full shop fabrication can be maintained rather than develop means for even partial field fabrication.

Until recently, nuclear fueled plants were usually sited near navigable water, so equipment was transported from the manufacturing

Table I

**REACTOR COOLANT SYSTEM EQUIPMENT FOR LIGHT WATER MODERATED REACTOR NUCLEAR STEAM SUPPLY SYSTEMS**

| PRESSURIZED WATER REACTOR | | | | | BOILING WATER REACTOR | | | | |
|---|---|---|---|---|---|---|---|---|---|
| ITEM | QUANTITY | WEIGHT | DIAMETER | LENGTH | ITEM | QUANTITY | WEIGHT | DIAMETER | LENGTH |
| **3800 MEGAWATT CORE THERMAL POWER** | | | | | | | | | |
| REACTOR VESSEL | 1 | 540 TONS | 22 1/2 FT | 41 FT | REACTOR VESSEL | 1 | 731 TONS | 22 1/4 FT | 62 FT |
| REACTOR VESSEL HEAD | 1 | 84 | 18 | 9 | REACTOR VESSEL HEAD | 1 | 90 | 22 | 10 1/2 |
| R.V. UPPER GUIDE STRUCTURE | 1 | 50 | 15 | 11 | R.V. CORE SHROUD | 1 | 50 | 16 1/2 | 22 |
| R.V. CORE SUPPORT BARREL | 1 | 100 | 15 | 32 | CORE SHROUD HEAD | 1 | 58 | 16 1/2 | 15 |
| CEDM COOLING SHROUD | 1 | 18 | 14 3/4 | 7 3/4 | STEAM DRYER ASSEMBLY | 1 | 48 | 17 | 17 1/2 |
| STEAM GENERATOR - 2 LOOP | 2 | 760 EACH | 20 1/2 | 69 1/2 | | | | | |
| OR | | | | | | | | | |
| STEAM GENERATOR - 4 LOOP | 4 | 500 | 18 1/2 | 61 1/2 | | | | | |
| **5000 MEGAWATT CORE THERMAL POWER** | | | | | | | | | |
| REACTOR VESSEL | 1 | 800 | 24 | 51 | REACTOR VESSEL | 1 | 1000 | 25 | 70 |
| REACTOR VESSEL HEAD | 1 | 120 | 20 3/4 | 10 | REACTOR VESSEL HEAD | 1 | 130 | 24 1/2 | 11 3/4 |
| R.V. UPPER GUIDE STRUCTURE | 1 | 70 | 16 1/4 | 16 | R.V. CORE SHROUD | 1 | 70 | 18 1/2 | 24 |
| R.V. CORE SUPPORT BARREL | 1 | 140 | 16 1/4 | 41 | CORE SHROUD HEAD | 1 | 80 | 18 1/2 | 16 1/4 |
| CEDM COOLING SHROUD | 1 | 23 | 17 | 8 1/2 | STEAM DRYER ASSEMBLY | 1 | 67 | 19 | 19 |
| STEAM GENERATOR - 4 LOOP | 4 | 500 | 18 1/2 | 61 1/2 | | | | | |

site to the installation site by barge (Fig. 4). This is, by far, the most economical mode of shipment with costs of a few cents per ton-mile. Now, however, there is a trend in siting plants away from navigable water, as can be seen in Fig. 5, where the operating, under construction, and committed nuclear units are shown geographically along with the contiguous navigable waterways of the U.S. suitable for the passage of component barges. The components must be removed from the barge at the nearest practical landing and shipped overland to the power plant site by expensive, time-consuming methods that can require extensive enroute preparations to accommodate size and weight.

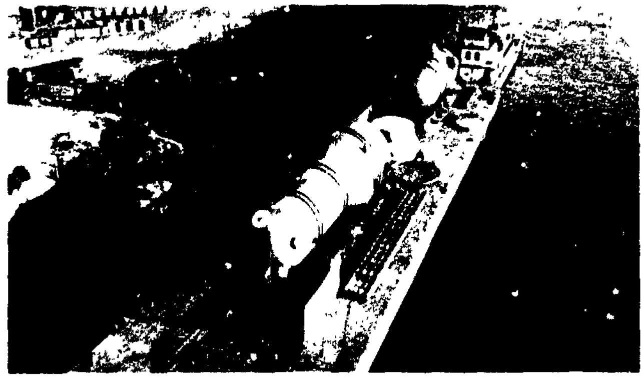


Figure 4: Barge shipment of nuclear components

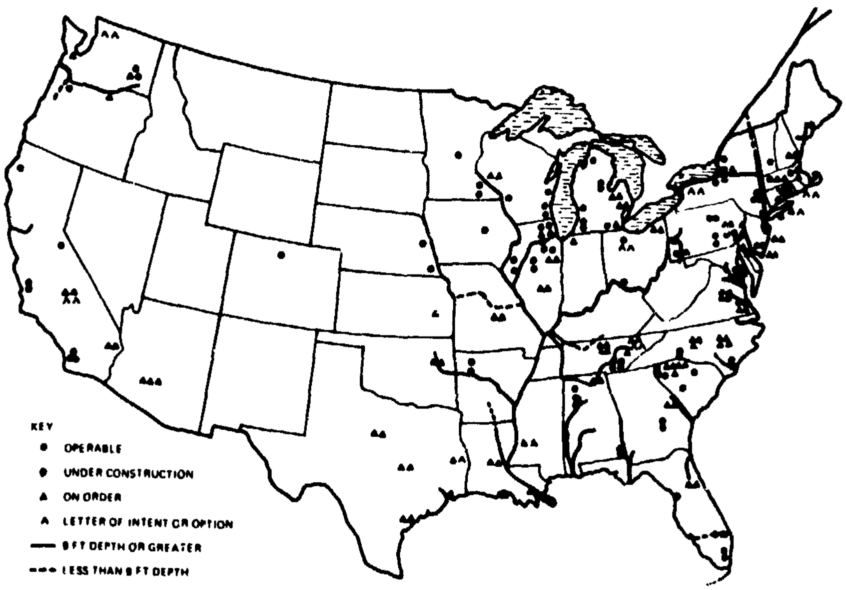



Figure 5: Central station nuclear power plants and navigable waterways

Figure 6 illustrates one method of transporting these components either on highways or on suitably prepared surfaces. The average speed is about one mile per hour. Though varying widely depending on the specifics of the route, cost may range from around \$5 to well over \$20 per ton-mile. Since the height of the load vehicle combination approaches 30 feet, much of the cost of transport by this or other highway modes can be due to the necessity of either moving overhead obstacles or bypassing them. The width of these vehicles, which is about 20 to 24 ft, can also present problems.

Figure 7 shows a proposed rail-borne method for transporting nuclear power unit components called a Schnabel car. Though potentially faster (operational speed may be as high as 15 miles per hour) and less expensive than highway modes, this mode of transportation has some limitations.

The Schnabel car makes use of the payload as the load carry-through structure and thus minimizes the overall height and center of gravity elevation by locating the base of the payload just above the rails. This reduces overhead clearance and lateral stability problems. This type of vehicle is in use here and abroad for transporting other, smaller, lighter objects. The Schnabel car shown in Fig. 8, which is a 12-axle car as contrasted with the 32-axle car shown in Fig. 7, is used to transport relatively small, fossil-fueled, fully

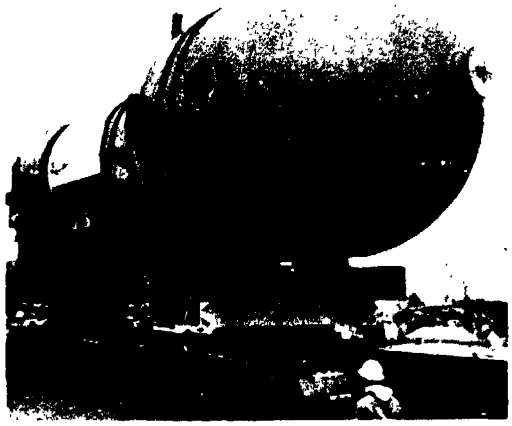


Figure 6: Steam generator on overland transporter

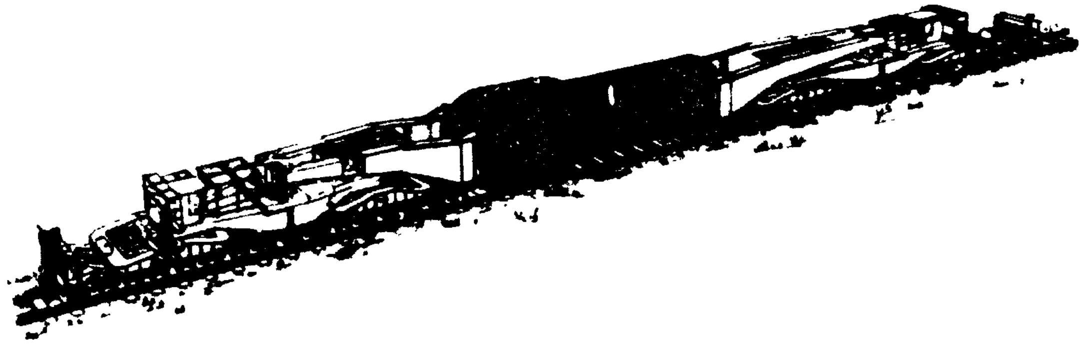


Figure 7: Nuclear component - Schnabel rail car of 800-ton capacity

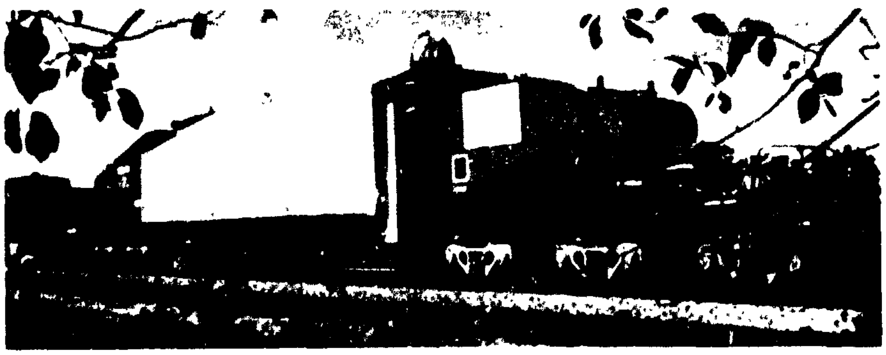


Figure 8: Schnabel car with shop-assembled fossil-fuel boiler

shop-assembled boilers to power plant and industrial sites. The Type

A boiler shown in this figure typically weighs a quarter of a million pounds and is 54 feet long, 20 feet high, and 13 feet wide. It can generate up to 300,000 lbs of steam per hour as compared to the larger fossil-fueled boilers that can generate over 9 million lbs of steam per hour or compared to larger nuclear units that can deliver up to 16 million lbs of steam per hour.

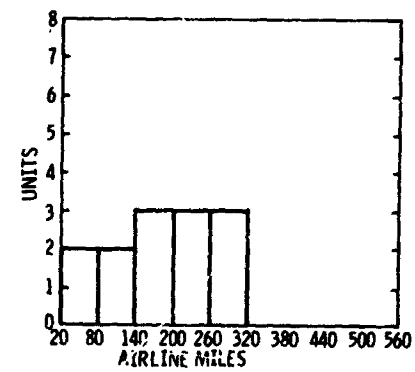
The siting trend away from navigable water is due to several reasons, among which are the rapidly increasing cost of suitable water edge real estate, a number of safety regulations (such as exclusionary (low population) zone regulations), and environmentalist pressure to minimize plant thermal discharges to bodies of water previously considered suitable as cooling water sources. Those bodies of water used to provide cooling for the steam condensers are, in general, the locations where there might be large population centers. Exclusionary (low population) zone regulations, intended to limit the population density around nuclear power plants, are, in effect, forcing the plants away from the larger bodies of water suitable as waste heat sinks. Since, as Fig. 5 shows, many of these bodies of water are also the navigable waterways of the U.S., the net effect is to force power plants to be located where transport of components overland becomes mandatory if fabrication and quality assurance testing at the site is to be minimized.

One of the reasons siting away from large bodies of water is possible is the development of closed-cycle cooling techniques using cooling towers of various types, spray ponds, or cooling ponds. In general, the water needs of these types of cooling systems are relatively small compared to open cycle cooling and are limited to water lost by evaporation and windage. In effect, the heat sink becomes the atmosphere. This is done by transferring the waste heat from the steam condenser via a closed, water loop to the cooling tower or pond which, in turn, transfers it to the atmosphere. In doing so, however, thermal inefficiencies are introduced that reduce power output for a given physical size unit. In order to maintain a given unit power output, unit physical size has to be increased, thus increasing capital costs. These same added inefficiencies also increase the use of fuel, thus increasing operating costs.

Despite the increasing cost of nuclear power plants, which some have estimated will rise to over $1000 per kwe by 1990, the economic advantage of nuclear power is even more pronounced today, due, in large part, to the ever increasing cost of fossil fuels.

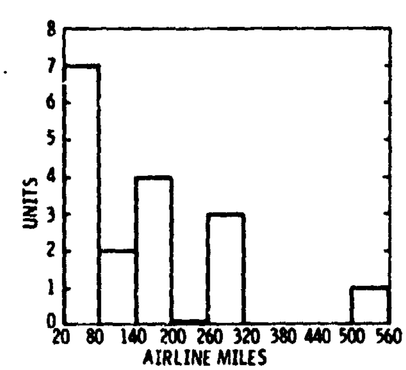
Indications are that the trend to siting away from navigable water will continue. Of the 36 domestic nuclear units booked industry wide in 1973, 14 require overland transport of large, heavy components for distances ranging from 50 to 400 miles. Figure 9 indicates the distribution of units committed as a function of distance from nearest navigable water to plant site. Because of the frequent large disparity in distances for a given plant site depending on the transport mode involved, Fig. 9 is based on straight-line distances from barge landings to plant sites. If all light water reactor coolant system equipment that could benefit from a more economical overland transport mode is included, there will be a total transport requirement of nearly 5,100,000 ton-miles/year in the early 1980s. Not all units booked in 1973 are scheduled for start-up at the same time; at present, start-up ranges 8 to 10 years from the booking date. Thus, the heavy equipment, which is generally shipped about three years before the start-up date will be arriving at the various sites over a spread of years. It is expected that in succeeding years the same sort of delivery time-spread will occur.

Though it is still too early to draw final conclusions from the nuclear sales record of 1974, data through the end of June indicates that the trend to remote siting is continuing and possibly increasing. Figure 10 gives the mileage distribution, not only for plants booked up to the end of June 1974, but also bids presently being evaluated and future unexercised options. Whereas in 1973, 36% of the units booked were for location at sites more than 20 miles from navigable water, it appears that in 1974 up to 40% will be remotely sited.




Represents Transport Requirements of 5, 104, 700 ton-miles

Figure 9: Distance of landlocked nuclear unit sites from navigable water for units booked in 1973




Represents Transport Requirements of 5, 400, 000 ton-miles

Figure 10: Distance of landlocked nuclear unit sites from navigable water for units booked, under construction, or on option in 1974

## INDUSTRY GROWTH PROJECTIONS TO THE YEAR 2000

In order to justify the development, testing, and certification of a new transport mode, the size and growth of the nuclear power plant fabrication industry must be projected allowing also a reasonable amount of time to get some use from the new transport mode. For this purpose, the future of the industry to the year 2000 is estimated. This estimate relies very heavily on the studies of the U.S. Atomic

Energy Commission as discussed in the WASH-1139 Report, "Nuclear Power Growth, 1974-2000," dated February 1974. Based on the "Case D" projection in this AEC report and assuming an increase in average unit size, it is expected that over 700 nuclear units will be built in the period from 1981 to 2000, representing nearly 1,000,000 Mw of installed electrical power and an investment by the utilities of about $700 billion. It is estimated that from 50 to 70% of these units will be located where the heavy components may have to be transported appreciable distances overland. As mentioned before, overland transport of these components by rail or highway will be difficult because of the size of the components. Rail and highway route clearances are sometimes not adequate to accommodate these large loads, so very expensive modifications to route-side and overhead structures and obstacles may have to be made, or else detours taken, in some cases, involving intermodal transfer. Figure 11 provides a graphic picture of the estimated number of LWR nuclear units that will be remotely sited versus year of shipment of heavy components for these units. Tables II and III provide a detailed breakdown of the number of components of each type estimated to be shipped per year to the year 2000.

Note that the data given in Fig. 11 and these tables do not include such reactor coolant system equipment as the pressurizer, reactor coolant circulating pumps and connecting pipe, all of which might also be shipped by air if the economics were favorable. Also, the information does not indicate the additional potential market for the transport of intermediate size components due to a potential shortage of ground-based transport equipment.

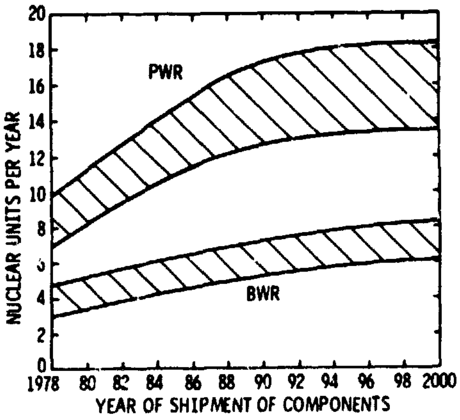



Figure 11: Nuclear units remote from navigable water

To provide some perspective on the dollars involved in transporting equipment by land-based means, cost data estimates from several sources have been plotted in Fig. 12. In evaluating the data, it must be recognized that each project is a special case. The problems and costs encountered in one case can be very different from those encountered in another. This accounts in part for the large scatter in the data.

## SUMMARY

Of alternate modes investigated to obtain relief from the restrictions and costs of ground-based overland modes, the most likely to provide a good solution by relaxing load dimensional limitations may be an airborne mode based on the use of lighter than air technology. Part or all of the load could be carried externally, greatly relieving restrictions on load size and shape. (Vehicle speed could be kept low enough to preclude the necessity of streamlining.) This mode would not require extensive and expensive landing facilities in remote areas. Payload weight would still present a formidable problem and much work would have to be done to develop vehicles of adequate weight-lifting capability. The development of airborne means to deliver the heaviest

NSSS components could begin with considerably lighter, but still large industrial products.

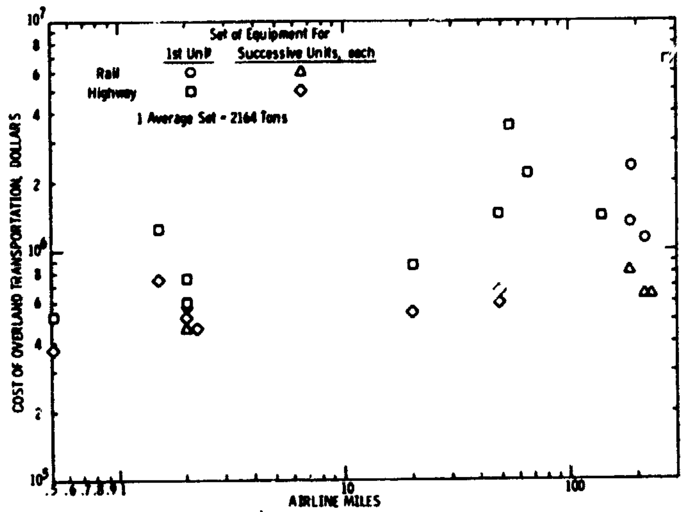



Figure 12: Cost of overland transportation of nuclear components

## Table II

PRESSURIZED WATER REACTOR ITEMS SHIPPED OVERLAND/YEAR (4)

| | RV | CSB | UGS | RVH | CEDM COOLING SHROUD | 2 LOOP S.G.(3) | 4 LOOP S.G.(2) | GEN. STATOR | TOTAL PWR ITEMS | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1978 | 7-10 | 7-10 | 7-10 | 7-10 | 7-10 | 8-10 | 12-2[illegible] | 7-10 | 6[illegible]-90 | (1) |
| 1979 | 8-11 | 8-11 | 8-11 | 8-11 | 8-11 | 8-12 | 16-20 | 8-11 | 72-98 | (1) |
| 1980 | 8-11 | 8-11 | 8-11 | 8-11 | 8-11 | 8-12 | 16-20 | 8-11 | 72-98 | (1) |
| 1981 | 8-12 | 8-12 | 8-12 | 8-12 | 8-12 | 8-12 | 16-24 | 8-12 | 72-108 | (1) |
| 1982 | 9-12 | 9-12 | 9-12 | 9-12 | 9-12 | 10-12 | 20-24 | 9-12 | 84-108 | (1) |
| 1983 | 10-14 | 10-14 | 10-14 | 10-14 | 10-14 | 10-14 | 20-28 | 10-14 | 90-126 | (1) |
| 1984 | 10-14 | 10-14 | 10-14 | 10-14 | 10-14 | 8-12 | 24-32 | 10-14 | 92-128 | (1) |
| 1985 | 11-15 | 11-15 | 11-15 | 11-15 | 11-15 | 6-10 | 20-40 | 11-15 | 92-140 | (1) |
| 1986 | 12-16 | 12-16 | 12-16 | 12-16 | 12-16 | 4-6 | 32-52 | 12-16 | 108-154 | |
| 1987 | 12-16 | 12-16 | 12-16 | 12-16 | 12-16 | 4-6 | 32-52 | 12-16 | 108-154 | |
| 1988 | 12-16 | 12-16 | 12-16 | 12-16 | 12-16 | 4-6 | 32-52 | 12-16 | 108-154 | |
| 1989 | 12-17 | 12-17 | 12-17 | 12-17 | 12-17 | 4-6 | 32-56 | 12-17 | 108-164 | |
| 1990 | 13-18 | 13-18 | 13-18 | 13-18 | 13-18 | 6-8 | 28-56 | 13-18 | 112-172 | |
| 1991 | 13-18 | 13-18 | 13-18 | 13-18 | 13-18 | 6-8 | 28-56 | 13-18 | 112-172 | |
| 1992 | 13-18 | 13-18 | 13-18 | 13-18 | 13-18 | 6-8 | 28-56 | 13-18 | 112-172 | |
| 1993 | 13-18 | 13-18 | 13-18 | 13-18 | 13-18 | 6-8 | 28-56 | 13-18 | 112-172 | |
| 1994 | 13-18 | 13-18 | 13-18 | 13-18 | 13-18 | 6-8 | 28-56 | 13-18 | 112-172 | |
| 1995 | 13-18 | 13-18 | 13-18 | 13-18 | 13-18 | 6-8 | 28-56 | 13-18 | 122-172 | |
| 1996 | 13-18 | 13-18 | 13-18 | 13-18 | 13-18 | 6-8 | 28-56 | 13-18 | 112-172 | |
| 1997 | 13-18 | 13-18 | 13-18 | 13-18 | 13-18 | 6-8 | 28-56 | 13-18 | 112-172 | |
| 1998 | 13-18 | 13-18 | 13-18 | 13-18 | 13-18 | 6-8 | 28-56 | 13-18 | 112-172 | |
| 1999 | 13 18 | 13-18 | 13-18 | 13-18 | 13-18 | 6-8 | 28-56 | 13-18 | 112-172 | |
| 2000 | 13-18 | 13-18 | 13-18 | 13-18 | 13-18 | 6-8 | 28-56 | 13-18 | 112-172 | |

SIMPLIFYING ASSUMPTIONS:

(1) ALL ITEMS SHIPPED THESE YEARS ARE FOR 3800 MWt SYSTEMS
(2) 4 LOOP STEAM GENERATORS ARE SAME SIZE REGARDLESS OF POWER LEVEL
(3) 2 LOOP SYSTEMS ARE ALWAYS 3800 MWt
(4) BEYOND 1985, ALL 4 LOOP SYSTEMS ARE FOR 5000 MWt

Table III

**BOILING WATER REACTOR ITEMS SHIPPED OVERLAND/YEAR**

| | RV | RV CORE SHROUD | RVH | GEN. STATOR | RV SHROUD HEAD | RV STEAM DRYER | TOTAL BWR ITEMS |
|---|---|---|---|---|---|---|---|
| 1978 | 3-5 | 3-5 | 3-5 | 3-5 | 3-5 | 3-5 | 18-30 |
| 1979 | 3-5 | 3-5 | 3-5 | 3-5 | 3-5 | 3-5 | 18-30 |
| 1980 | 3-5 | 3-5 | 3-5 | 3-5 | 3-5 | 3-5 | 18-30 |
| 1981 | 4-6 | 4-6 | 4-6 | 4-6 | 4-6 | 4-6 | 24-36 |
| 1982 | 4-6 | 4-6 | 4-6 | 4-6 | 4-6 | 4-6 | 24-36 |
| 1983 | 4-6 | 4-6 | 4-6 | 4-6 | 4-6 | 4-6 | 24-36 |
| 1984 | 4-6 | 4-6 | 4-6 | 4-6 | 4-6 | 4-6 | 24-36 |
| 1985 | 5-6 | 5-6 | 5-6 | 5-6 | 5-6 | 5-6 | 30-36 |
| 1986 | 5-6 | 5-6 | 5-6 | 5-6 | 5-6 | 5-6 | 30-36 |
| 1987 | 5-7 | 5-7 | 5-7 | 5-7 | 5-7 | 5-7 | 30-42 |
| 1988 | 5-7 | 5-7 | 5-7 | 5-7 | 5-7 | 5-7 | 30-42 |
| 1989 | 5-7 | 5-7 | 5-7 | 5-7 | 5-7 | 5-7 | 30-42 |
| 1990 | 5-7 | 5-7 | 5-7 | 5-7 | 5-7 | 5-7 | 30-42 |
| 1991 | 5-7 | 5-7 | 5-7 | 5-7 | 5-7 | 5-7 | 30-42 |
| 1992 | 5-7 | 5-7 | 5-7 | 5-7 | 5-7 | 5-7 | 30-42 |
| 1993 | 5-8 | 5-8 | 5-8 | 5-8 | 5-8 | 5-8 | 30-48 |
| 1994 | 5-8 | 5-8 | 5-8 | 5-8 | 5-8 | 5-8 | 30-48 |
| 1995 | 5-8 | 5-8 | 5-8 | 5-8 | 5-8 | 5-8 | 30-48 |
| 1996 | 6-8 | 6-8 | 6-8 | 6-8 | 6-8 | 6-8 | 36-48 |
| 1997 | 6-8 | 6-8 | 6-8 | 6-8 | 6-8 | 6-8 | 36-48 |
| 1998 | 6-8 | 6-8 | 6-8 | 6-8 | 6-8 | 6-8 | 36-48 |
| 1999 | 6-8 | 6-8 | 6-8 | 6-8 | 6-8 | 6-8 | 36-48 |
| 2000 | 6-8 | 6-8 | 6-8 | 6-8 | 6-8 | 6-8 | 36-48 |

SIMPLIFYING ASSUMPTIONS:

1 ALL SYSTEMS DELIVERED TO 1985 ARE 3800 MWt
2 ALL SYSTEMS DELIVERED AFTER 1985 ARE 5000 MWt