CAPABILITY VS COST FOR SERVICING AND HANDLING SYSTEM CHOICES IN 200-BeV ACCELERATOR DESIGN STUDY

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Summary

Unprecedented size, residual radiation, and the need for quite reliable operation of the 200-GeV accelerator present new challenges in servicing and maintenance. Yet costs must not be disproportionately large. An example servicing solution is developed, and variations are investigated for costs. It is shown that large-percentage cost changes are not to be expected, but that small changes can represent millions of dollars. Therefore extraordinary care should be exercised in refining appropriate solutions. The era of thorough preconstruction mock-up work has arrived in the accelerator business!

Introduction

The unprecedented areal extent of the 200-GeV accelerator, and the intent to operate with beam intensities which develop significant residual radiation will usher in a new scale of values for handling and servicing facilities. To achieve a balanced accelerator complex, capable of coping efficiently with distress as well as with routine operations, the servicing function must be better integrated and more comprehensive than has been usual in the past. An applicable solution will be described here and, in a preliminary fashion, possible cost variations investigated. There is no pretense that this discussion will be either definitive or exhaustive. Rather, it is the result of a first long look in which we are attempting to define an example solution and then to obtain some perspective on possible cost ranges.

Utilization and Environment

Conceptual choices for handling and servicing systems depend upon the environment to be encountered, the nature and frequency of the operations to be executed, schedule and manpower considerations, and distances from central support facilities. For the 200-GeV accelerator, it is intended that beam intensities of 1.5×10^{13} pps will be routine, with a possible later escalation to 5×10^{13}pps. Routine scheduling calls for two consecutive days of non-operation every two weeks, with shutdowns several weeks long once or twice a year. Servicing personnel are to receive a maximum of less than half the permissible weekly radiation allowance during routine maintenance, i.e., not more than 50 mR per shutdown day.

The residual radiation environment within the main accelerator enclosure is expected to consist of several relatively active regions, principally at beam extraction stations, but 95% of the circumference will remain little affected. These have been termed "red" and "quiet" radiation regions, respectively. In the red regions immediately after turnoff, peak radiation intensities of 200 to 300 R/h are expected a foot away from the ends and opposite the gap of C magnets; these intensities will decay to 60 R/h in a week.[1] Plugs will be used in the C magnet gaps, and special shielding between the magnet ends, so that shielded vehicles need cope only with intensities of 10 R/h or less for extended periods. In the quiet regions at turnoff, residual radiation levels a foot away from the magnets are expected to be approximately 9 mR/h behind the magnet yokes, and 75 mR/h on the open C side and at the ends. In 24 hours these values will have decayed to approximately 3 and 25 mR/h.

As the accelerator design matures, this initial concept of appreciable residual radiation only at beam injection and extraction stations may prove an over simplification. It will probably be desirable to "shadow" particular regions, for example, the radio-frequency stations. Collimators for this purpose will cause local radiation increases. If the particle beam solidly intercepts the vacuum chamber, single-pulse local instantaneous temperatures of 700°C are plausible. To protect the vacuum chamber, sacrificial collimators will probably be used, again causing local radiation increases. It is always possible that a region of the accelerator may unexpectedly become radioactive. For these reasons it is considered prudent at this stage to have the remote-handling capability applicable anywhere on the accelerator.

An Example Solution

In developing the remote servicing concepts presented in the Design Study,[2,3] we followed four guidelines:

1. Recognize the great advantage of having the operator at the work site, viewing the work through a window, and using simplified extension tools as much as possible.
2. Avoid a manipulator development program within the project, if possible. Use proven existing components and provide flexibility so that future advances in technology can be incorporated.
3. Integrate the servicing system with the accelerator. Design accelerator components for the servicing function as well as for the accelerator function. Emphasize modularity.
4. Do not require that remote handling be used unless there is no alternative. If a simple relocation of a component allows servicing by unshielded personnel, do so.

Placing the servicing technician at the work site behind several inches of dense shielding requires both a heavy vehicle and at least one major servicing aisle all around the accelerator. From a servicing viewpoint, C magnets are an opposite-handed structure. Pairs of magnets alternate in facing first the inner, and then the outer radius walls of the tunnel. For unshielded personnel in the quiet radiation regions, components requiring maintenance should always be placed behind the C magnet yoke. In case of unexpected radiation increases, the shielded vehicles must also have access to these components. Thus two service aisles, one on each side of the accelerator ring, appear necessary. An advantage of this arrangement is that, in times of trouble, two vehicles can reach the same component -- one from each side.

It is desirable that the utilities distribution system also be maintainable from the shielded vehicles when necessary. If they are placed on the inner radius wall this capability is obtained. When so placed, the relatively wide servicing aisle develops a second advantage. Temporary shielding can be erected between the utilities and the accelerator, allowing repair or modification by personnel working outside of the vehicles.

The distance from central shop and support facilities to any given point on the accelerator is not an inconsequential factor. To forestall developing the situation of the proverbial plumber always going back to the shop for another tool, standardized but comprehensive sets of tools and test equipment should be provided with each work crew entering the enclosure. A different class of vehicle, termed "Work Center," is proposed for this purpose. It would have the multiple functions of being a street car, a traveling tool room and drawing file, power station for tools and illumination, and become a locomotive pulling a flat car when bulky or massive loads must be introduced. If it is lightly shielded, supervisory personnel can be protected from the cumulatively significant radiation in the quiet regions when they work long hours during times of trouble.

Within the enclosure both types of vehicles could be powered in common with the cranes from overhead electrification. Vehicles must not become immobilized for long periods in red radiation regions. Therefore, in case of power failure, a second self-sufficient source of power must be available. Batteries will be incorporated for this purpose. These batteries will routinely be used to negotiate the access sections between the tunnel and the outdoors, thus saving the cost of electrifying these branches.

The extra cost of a railway system is believed to be warranted for the service vehicles. Rails insure that no "unguided missiles" will be operating near the accelerator. Good register, ease in positioning and a solid work platform are further advantages. Power requirements are minimized since tractive effort on rails may be as little as one-sixth that required for rubber-tired vehicles. This is important when considering battery power.

The transfer agent used with the rail system must have maximum flexibility and universal applicability. For this function, there is no real substitute for overhead cranes.[4] No other system offers the comprehensive coverage, unobstructable right-of-way, ease of parts positioning during installation, or compatibility with other more specialized handling devices. During normal operations some temporary obstruction of the rail vehicle aisles may occur. During times of trouble, with very intensive work at a local focus, it is almost certain that the floor will be blocked. The unobstructed right-of-way for the crane will then be essential.

Operations people believe that, if distress of an unexpected nature in the red radiation regions cannot be quickly resolved with the shielded vehicles, traditional methods will be resorted to. Temporary shielding will be erected, allowing personnel to work as unencumbered as possible. Such temporary shielding can become massive, and both adequate space and a highly flexible means of placing it must be available. No other system would meet these requirements as flexibly as overhead cranes.

Both existing large AGS machines have overhead handling. These rights-of-way are beginning to be utilized for the remote handling of targets and for remote surveillance of the operating machine. At the existing machines these functions will continue to be developed during the construction of the 200-GeV accelerator. If the overhead crane is supplied, and not committed to routine remote maintenance, these developing techniques can be adapted to the large accelerator later on.

Variations and Costs

After this brief introduction to the system model, let us consider possible variations and then obtain some perspective on cost differentials. To do this one should investigate examples beyond those which would be considered acceptable, particularly on the minimal side. Otherwise, how would one know he has gone far enough?

Possible variations include changes in height and width of the enclosure, changes in crane capacity, one-sided or double-sided servicing, and various options in facilities distribution. These in turn depend to some extent on variations in the accelerator. Estimated capital costs for affected components are shown in Table I. These costs derive from the Design Study Site Example A.

Whether the accelerator can be serviced from one side is of most consequence with respect to costs. This is still an open question within the Design Study Group. H magnets with shielding between the coils can be considered one-sided servicing structures with respect to residual radiation. Thus, components requiring surveillance and possible maintenance, such as water-line insulators and interlocks, and water and power connections, could all be grouped facing one major servicing aisle. In the quiet radiation regions, the other aisle need be only wide enough for occasional walk-through surveillance (for purposes such as visual inspection of insulation). In red regions such inspection might be done by closed-circuit TV from the shielded vehicles. However, this aisle should still be sufficiently wide to allow the introduction of a man and temporary shielding during times of trouble.

If shielding material is inserted in the open side of those C magnets which face one aisle, then this one-sided servicing option is also available with the C configuration. It is presumed that removable plugs would not seriously compromise the significant advantage of direct access to the vacuum chamber and magnet gap which the C configuration offers.

In the red regions very dense plugs are required (approximately 500 lb/ft^3) to make the gap shielding equivalent to the yoke shielding for the remote-handling vehicles. Such shielding would be much too expensive to apply in the quiet regions. However, it is estimated that heavy concrete with barite aggregate would reduce the magnet contribution to residual radiation from approximately 65 to 5 mR/h at turn-off, and to 3 mR/h a day later. This may be sufficient to allow the one-sided servicing. Such plugs for the 232 gradient magnets facing the inner aisle would cost approximately $0.4 million, but the enclosure width might be reduced and the rails and overhead electrification omitted on one side.[5]

Variations in crane type and capacity will affect the enclosure size as well as the crane and crane-runway costs. A 20-ton capacity was chosen so that two 20-ton cranes working together could handle the largest gradient magnets. In addition, they would transfer the servicing vehicles from the inner to the outer radius servicing aisles. Using the cranes for this function avoids duplicating the vehicle access portals on both sides of the magnet enclosure, a savings which approaches $1-1/2 million. At first glance this liftover feature appears awkward and hazardous. However, like changing the wing sweepback on an inflight airplane, if it is the appropriate solution it can be effectively and safely implemented.

One-sided servicing eliminates the need for this liftover feature. The exchange of the largest gradient magnets is expected to be an infrequent occurrence. If a special 40-ton side-handling device were provided for the largest magnets, the next major handling capacity requirement would be 10 tons, or a pair of cranes could handle 20 tons. The largest temporary shielding blocks one would expect to handle within the enclosure would also be about this weight. The minimal capacity it ould seem worthwhile to supply, considering enlosure and crane runway costs, would be in the 3- to 5-ton range. The lifting ability of such cranes is discouragingly restricted compared with possible loads. For less than 3 tons, different devices, such as light erectable gantries, should be considered.

Figures 1 through 4 show four examples covering the range of these variables, and Table II is an estimate of the associated cost changes. Example I describes a full double-sided servicing system with a conventional 20-ton overhead crane. Example II shows double-sided servicing but with the more expensive "Flying Trolley" crane, with which the hoist is fixed to the bridge and can thus utilize the otherwise wasted space next to the overhead air ducting system. Overall reductions of approximately half a million dollars are expected to result from this simple change. Examples III and IV show minimal systems with the plugged C magnets and 10-ton crane handling capacity, and the H magnet with the even smaller 3-ton cranes, respectively. Cost reductions of $3 million and $4-1/4 million respectively might be expected.

Conclusions

Available space is a most significant factor in coping with trouble in radioactive components. For the examples given it is important to note how the tunnel volume decreases much more rapidly than the costs -- approximately a factor of 3, as shown in the bottom lines of Table II. It is therefore proportionately more difficult to make cost reductions than it is to accommodate a slightly increased need for space.

A full-size wooden mock-up of the magnet enclosure, magnets, and shielded vehicle (Fig. 6) is beginning to become useful in assessing the space actually required for employing the handling concepts outlined. Indications are that the enclosure widths described on drawings may be somewhat parsimonious. As an example, let us presume the one-sided servicing concept can be adopted. If the plugged C magnet is used, the present state of knowledge indicates the arrangement shown in Fig. 5 would be a reasonable choice. This is considerably removed from the minimal cases, yet would show cost reductions of $1-2/3 million compared to those shown in Fig. 1.

From these considerations one can conclude that large-percentage changes in the enclosure costs are not to be expected unless drastically revised handling and servicing system concepts are adopted. However, small percentage changes represent millions of dollars. Thus, extraordinary care in investigating, substantiating, and refining proposed systems will reap large dollar rewards. The era of thorough full-scale preconstruction mock-up evaluation has arrived for the accelerator business!

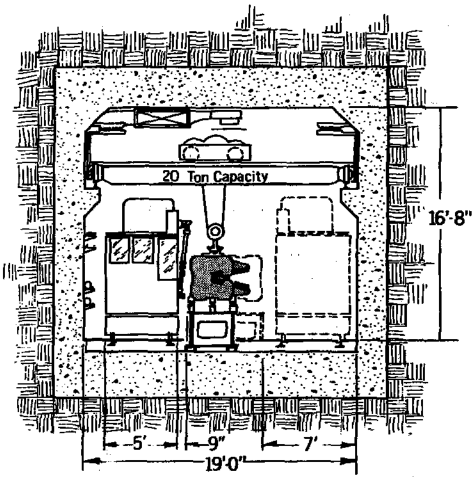

Fig. 1. Double-sided servicing conventional 20-ton crane.

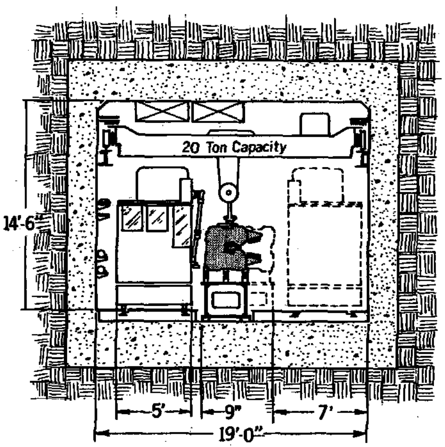

Fig. 2. Double-sided servicing "Flying Trolley" 20-ton crane.

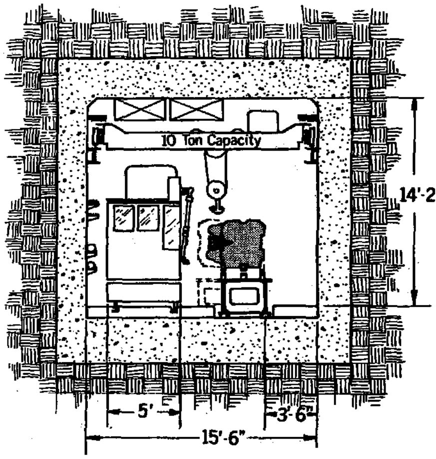

Fig. 3. Minimal section and C magnet 10-ton crane.

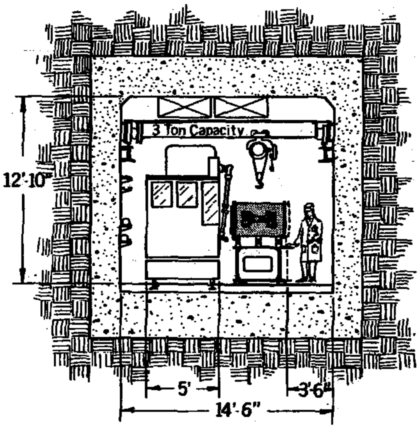

Fig. 4. Minimal section and H magnet 3-ton crane.

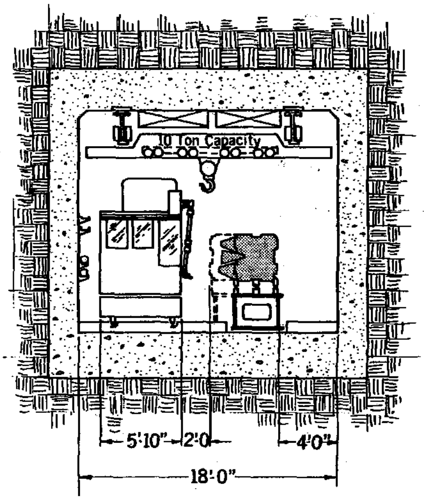

Fig. 5. Best present guess—space and arrangements for single-sided servicing.

TABLE I

ENCLOSURE & HANDLING SYSTEMS COSTS FOR COMPRESSIBLE SOILS SITE
All Costs Include 12 ½ % A&E and 15% Contingency

ENCLOSURE STRUCTURE COSTS (Main Ring— 16⅔' high x 19' wide inside)	
Typical Section (10,976 ft)	$11,200,000
Non-Typical Section	7,200,000
Sub-Total Enclosure	$18,400,000
Earthwork	7,500,000
TOTAL STRUCTURE AND SHIELDING COVER	$25,900,000
Rails in Floor (two tracks)	1,460,000 *
Servicing Vehicles	450,000
Crane Rails & Supports (20 ton Cap.)	700,000 *
Electrification (two sides)	180,000 *
Cranes (10 units 20 tons each)	410,000
TOTAL COST OF ITEMS CONSIDERED	$26,760,000
ENCLOSURE INCREMENTAL COSTS	
Reduce Width 1 ft, Reduce Cost	$440,000
Reduce Height 1 ft, Reduce Cost	$350,000

* Included in enclosure structure costs

Footnotes and References

* **Work sponsored by the U. S. Atomic Energy Commission.**

1. **Roland Krevitt, Various Data and Assumptions used for Calculating Radiation and Stay Times in Target Areas, Lawrence Radiation Laboratory Report, UCID-2887, Apr. 26, 1966.**

2. **200-BeV Accelerator Design Study, Lawrence Radiation Laboratory Report, UCRL-16000, June 1965.**

3. **200-BeV Accelerator Preliminary Project Report, Lawrence Radiation Laboratory Report, UCRL-16606, Jan. 1966.**

4. **G. R. Lambertson, E. Hartwig, W. Salsig and W. Hartsough, Re-Examination of Magnet Enclosure Handling System Requirements, Lawrence Radiation Laboratory Report, UCID-10196X, Oct. 13, 1965.**

5. **J. Satti, Magnet Gap Shielding, Lawrence Radiation Laboratory Report, UCID-2886, Jan. 23, 1967.**

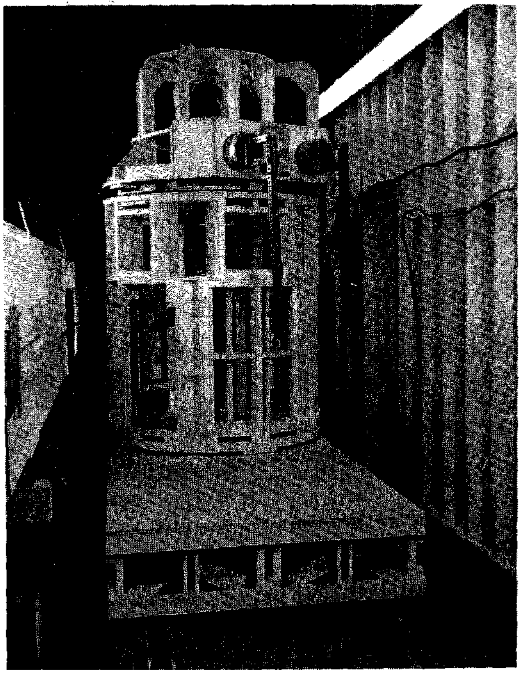

Fig. 6. Wooden mock-up with dummy shielded manipulator vehicle.

Table II. Cost Changes for Various Arrangements

		Fig. 1 200 BeV Accelerator Design Study June 1965	Fig. 2 Preliminary Project Report Jan. 1966	Fig. 3 Plugged "C" Magnet 10 Ton Crane and Minimal Section	Fig. 4 "H" Magnet 3 Ton Crane and Minimal Section
1.	Internal Dimensions	16'8" x 19'0"	14'6" x 19'0"	14'2" x 15'6"	12'-10" x 14'6"
2.	Cross Sectional Area	316 sq ft	275 sq ft	220 sq ft	186 sq ft
3.	Crane Capacity	20 ton	20 ton	10 ton	3 ton
4.	Estimates Cost Changes				
	Enclosure Height	----	-$760	-$870	-$1,340
	Enclosure Width	----	----	-1,540	-1,980
	Cranes	----	+310	+130	-320
	Crane Rails	----	----	-200	-350
	Floor Rails	----	----	-730	-730
	Overhead Electrification	----	----	-80	-80
	Floor-Mounted Transfer Equipment	----	----	+160	+450
	Magnet Gap Shielding	----	----	+400	
	NET Estimate Changes	0	-$450	-$2,730	-$4,350
	% Reduction (Base = $28.7 million)	0	< 2%	< 10%	15%
	% Reduction in Enclosure Volume	0	13%	30%	41%