INDUCED RADIOACTIVITY & REMOTE HANDLING METHODS FOR ACCELERATORS

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Abstract

The improvement of accelerators for greater beam intensity brings on problems of high induced radioactivity in parts and hardware associated with these machines. Data showing the magnitude of induced activity at several existing installations are tabulated to forecast the ultimate levels.

Magnitudes of several hundred R/hr. are predicted, thus showing the need for a logical approach to the problem in new machine design parameters and in remote handling.

The proposed modifications of present accelerators are presented showing the different approaches taken and the philosophy upon which their criteria are based. Design in some cases is based upon the ultimate activity levels expected, while others plan to make improvements as the activity grows. Regardless of the approach, definite design features are mandatory to make them compatible to remote handling.

These features take into account the inaccessibility to the activated equipment and the need for rapid assembly and disassembly. Modular design of apparatus with quick disconnect means for both the mechanical and electrical coupling is presented to fulfill the above needs.

A review is made of the existing remote handling equipment and systems showing their shortcomings or possible application to accelerator work. This is supplemented with an explanation of what features must be present in remote handling systems to make them usable for accelerator use.

Manipulators and remote handling devices used in hot cells are designed for operation within the confines of limited and selected space. Large accelerators, on the other hand, require highly maneuverable equipment that can work in large working volumes. Examples of apparatus of this nature are explained together with auxiliary support systems for operation from remote distances, including viewing equipment.

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Introduction

The state of the art in various engineering disciplines has been advanced immeasurably in the building of accelerators. Magnet design has progressed a great distance in the past 15 to 20 years. Power supplies, unheard of in industry a few years ago, appear unbelievable when one considers the regulation and precision of current control required for the guide fields and focusing of beam lines. High vacuum found only in vacuum tubes and laboratories are commonplace in huge machines. There seems to be no phase of engineering that hasn't been put to task in building a successful accelerator, be it electrical, mechanical, civil or chemical engineering. The accomplishments in each of these disciplines seem too numerous to mention when one looks back. Although all these seemingly impossible things have been done, one must look ahead and ponder when one hears of what is to come in future accelerators and the challenges which have yet to be met.

Induced Radioactivity

One area of work, that produces many challenges to all phases of engineering, is the induced radioactivity that will be present as a result of improvements on present accelerators and contemplated higher energy machines.

The problem of induced radioactivity in the present operating machines can be classified as an inconvenience. With proper precautions, most of the work has been done by the direct contact with the equipment. As the present machines are being improved for greater outputs, a plateau or threshold is reached where human contact with the work is not advisable or possible without serious consequences to the individuals being exposed.

The seriousness of the induced activity problem becomes very apparent when one observes the dosage readings of present machines. Figure 1 shows the physical layout of the Brookhaven AGS. This accelerator uses C magnets. This fact is mentioned to point out that this machine has very little self-shielding on one side of each of its magnets. The beam tube is visible in the open portion of the C magnet. Induced activity has been shown on Fig. 2.[1] Although no dosage readings were obtained in this form for the CERN machine, their induced activity problem is quite similar to the Brookhaven machine since they are similar in construction.[2]

Figure 3 shows the arrangement of the Argonne ZGS. The levels of induced activity at the ZGS are shown on Fig. 4. From the measured levels, we have extrapolated the activity as the machine output is increased to 10^{13} protons per second. The self-shielding effect of the picture frame cross-section is quite evident along each octant section. Induced activity is of concern to the Berkeley Bevatron people. Their target equipment and extraction magnet reach levels of 15 to 25 R at their present operating intensity of 2.5×10^{12} protons per pulse.

Figure 5 shows the trends of levels to be expected from various types of machines, including the future 200 BeV and higher BeV machines.[3] These curves are not intended to give absolute values because they have been extrapolated in terms of beam intensity. The increase due to energy increase in future accelerators has not been included in the curve.[4] The activity increase due to energy increase is not a straight line function and at higher energies, its effect will be small compared to the intensity increase. Although the curve tends to go skyward, it must be remembered that higher energy machines using conventional magnet design will be physically much larger and the area being bombarded by the stray particles is greater. The intensity of residual activity is a function of the number of interactions per unit area. So in all probability the increased area and improved shielding on the machine itself, quiet areas might not increase beyond what is predicted for the present improved machines.

The target areas will have a tendency to increase at a greater rate than the quiet areas since, in most cases, the target and extraction equipment will not increase in size. Again, some hope can be expected even in the target areas because with increased proton beam and at higher energies, multitargets will be used and the average particle bombardment per target will tend to reduce the activity level.

Regardless of what machine one may make predictions for, it is very obvious that new and additional engineering criteria must be used in designing higher output machines. Based on AEC allowable limits, Fig. 6 has been prepared to show the time a person can work in various radiation fields under several conditions. In the presence of high induced activity, three lines of defense are available: 1) the use of shielding, 2) increasing the distance from the object, and 3) allowing the induced activity to decay to a workable level.

This problem of handling highly activated materials may be new to the accelerator people; however, it has been developed to a great degree by the nuclear reactor people. In recent times, NASA has embarked on developing remote control systems for their installations. The Navy is also starting a program of remote handling for deep sea rescue, repair and exploration. To date, since these programs are relatively new, no significant advancement has been accomplished over the means used in the reactor field.

Remote Handling Manipulators

In making an extensive study of what is available in proven remote handling hardware, it is clear that much remains to be done in applying the equipment to accelerator use. The majority of the remote handling equipment which has been developed for reactor or laboratory use is made for operation in relatively small volumes. The work is taken to a facility where the manipulation is performed in hot caves. Here, the work is done under more ideal conditions by what is considered direct viewing through shielding windows, along with proper lighting. Accelerators, on the other hand, present a problem in that the remote handling manipulators must be taken to the work. Direct viewing, in most cases, is impossible and other means of viewing must be developed. In comparison, the working volume of an accelerator seems to be limitless.

Before we go into details and suggestions of remote handling methods for accelerators, Figs. 7 and 8 are presented as a resumé of remote handling equipment that is commercially available today. This brief outline is presented to acquaint you with the equipment and some of the terminology used in the remote handling manipulator circles. For a more comprehensive explanation of manipulators, your attention is directed to the proceedings of the Conference on Remote Systems Technology, ANS, and in particular, the paper by R. Goertz, Manipulator Systems Development at ANL.[5]

Although the switch operated or velocity-controlled type of manipulator, Fig. 7, reproduces most of the movement of the operator's arm and shoulder plus some of the movements of his body, it possesses no feedback of force. The operator must rely solely on viewing apparatus to verify his accomplishments.

The master slave, both mechanical and electrical, type of instrument, Fig. 8, in most cases is a lighter duty device. It has the advantage of feel. Consequently, it has been favored for all delicate work since it reproduces the operator's motions and sense of feel to a great degree.

The switch-operated machine is usually a heavier duty apparatus and it is quite likely that for accelerator use it would be the primary tool for accomplishing a job with the master slave type as a supplementary system. This is particularly true if one considers the presently available commercial manipulators.

Modification of Accelerators

The manipulators are indeed a very fascinating piece of apparatus; however, it must be borne in mind that they are only part of the remote handling system that is necessary to cope with problems of maintaining, repairing or changing an accelerator. Even with the finest manipulators, the rate of performing typical hot laboratory work is at least 1/8 the speed of doing the same work by hand. [5]

As accelerators get larger and more complicated, they also become more expensive and their operation becomes more costly. The demand for experiment time on larger machines is great, so all in all the downtime of an accelerator must be kept to a minimum to get the best efficiency from such an installation.

With the ambient working conditions becoming more hazardous due to induced activity and the inherent inefficiency of the tools with which to work, it is obvious that additional engineering criteria must be considered in the future accelerators. The design of the accelerator and particularly that of its auxiliaries must be streamlined to make repair, maintenance and changes more simple to reduce the downtime.

In the case of the present accelerators, the amount of facility alteration required is contingent upon the expected rate of growth of induced activity and the ultimate levels one can expect. The AGS, for instance, with its high rate of induced activity growth and because of its present arrangement of auxiliaries and service equipment, requires a sizable amount of improvement to minimize the amount of equipment to be affected by residual activity. Figure 9 shows the proposed changes to the AGS installation. [6] They are recommending the removal of all auxiliaries to a second ring and pipe the resultant services to the accelerator itself through vertical openings. The earth shielding and distance from the accelerator will reduce the work to be done by manipulators to a minimum.

Even with all these changes, many features must be incorporated in the magnets, connections, piping and the like to minimize the work. These general features are in the same category for all machines and will be pointed out as engineering criteria later.

At the ZGS, the conditions are quite different because of the self-shielding of the magnet structure. Not much is required in the way of facility modifications, but engineering changes are required in the machine itself. (Fig. 10, "Present L-3 Box and Equipment;" Fig. 11, "Proposed New Design.")

Straight sections are being designed so that they can be sectionalized and readily removable for equipment changes. The smaller dimensions of the straight sections will result in improved dimensional stability of the targetry mechanisms due to the shorter mechanical moment.

The auxiliary or dc correction magnets constitute a major portion of equipment around the ZGS. These are being redesigned to give much simpler cooling and power connections. An alignment fixture will permit the use of remote handling equipment and so will the newly designed fastening features.

Engineering Criteria

In explaining some of the features being incorporated in the ZGS, it is impossible not to mention the criteria required in new accelerators to make them compatible to remote handling schemes. It is best that we enumerate these features for all accelerators and the advantages they present in streamlining an accelerator.

1. Sectionalizing large apparatus.
2. Modularizing all auxiliary equipment.
3. Use of quick disconnect fasteners.

In sectionalizing large apparatus, one must include the following criteria. It must be readily replaceable and preferably arranged so that it can be lifted vertically by overhead cranes. If the unit is a large portion of a machine, the sections should include all of the appurtenances required for the complete unit. Connections to the unit from main headers (water, air, vacuum, etc.) should be designed to provide minimum connections. These connections must then be of the quick disconnect type. Instead of bolted joints, as in the case of presently used flanges or power lugs, overcenter clamping assemblies should be used. The closure of the quick disconnect should be a simple toggle action which can be actuated by a crane hook or simple motion of a remote manipulator.

The section of equipment should include guides or a base to fit on supports that require a minimum of alignment. If alignment is necessary, it is better to include that feature in the support base a separate entity from the removable section of the equipment. An example of these features is shown in Fig. 11 showing the proposed improved L-3 straight section of the ZGS. Here each section contains the equipment pertinent to the operation of the accelerator. The devices that fit into this section are inserted into the preassembled and prealigned ports.

Every effort should be made to make all sections look identical, especially as far as alignment guides, bases, service connections, etc., are concerned. In an approach of this nature, it is economically feasible to have spare sections. The use of spare units will aid in the repair of highly activated parts. The repair work can be done in more appropriate facilities without prolonging the downtime of the accelerator. If the repair of the substituted unit is not urgent, it can be allowed to rest until the decay of the activity level is such that conventional repair means can be used. Sectionalizing, as referred to in this paper, was applied to stationary parts of an accelerator, such as magnets, beam tubes, straight sections, etc.

Machinery and apparatus, like target mechanisms, diagnostic detector positioners and devices of this type, should be modularized. Modularizing refers to the packaging of the assembly. A target mechanism module should contain all the drives, motors, servos, readout transmitters and transducers in one unit. This unit must also contain the mountings that accept the mating flange on the straight section or beam pipe by means of a simple actuated clamping arrangement. When clamped, alignment and positioning of the basic device is done. From then on, the proper placement of the target and intelligence readout is done by the apparatus within the module itself. The module, if properly designed, should require simple handling that can be done by an overhead crane or with very few manipulations of the remote handling equipment.

In addition to its proper placement in the accelerator, service connections must be made by grouping them in an orderly manner on a fixture which require a simple plug-in operation.

Clamping or pressure connections can be done by mechanical latching features or power actuators. This type of design has been used extensively in the Fuels Technology Center at EBR II in Idaho. All the machinery used in the reprocessing of spent fuel rods used in a nuclear reactor have been built on the modular principle and require simple movements to assemble and disassemble intricate machinery.[7, 8]

With the simplification of parts of the accelerator and its auxiliaries by incorporating timesaving features, the types of work expected of a remote handling system have been somewhat narrowed. In most cases, the complexity and intricacy is still with the machine parts; however, the amount of work that need be done to these parts in the accelerator building is cut down considerably. Substitution of repaired or changed apparatus saves machine downtime which, in turn, also reduces the amount of work that need be done in a radiation environment.

Remote Handling

The method or remote handling system to be used is dependent on the characteristic of the machine and its facilities. Many remote handling devices and schemes have been reviewed with possible application to our problem.

The use of a shielded self-propelled mobile unit using conventional remote handling apparatus is shown on Fig. 12. The shielded cab affords protection for the operator. Although this unit has many fine features, it does possess some definite disadvantages. A vehicle like this weighs approximately 10 to 15 tons and the floor loading is about 1000 lbs./sq.ft. This will require that special attention be given to the type of floor on which this vehicle will be used. The internal size of the shielded cab limits the motion of the master portion of the manipulator which affects the coverage of the slave. The over-all outside dimensions prevent its use in tight quarters.

Some of the disadvantages of this unit can be overcome with the use of velocity-controlled type of manipulator mounted on a robot base, Fig. 13. This equipment permits the operator to be located in a safe location. Because of this privilege, one pays the price of viewing from a greater distance or the use of a closed loop television system. Being a floor operated device, it too has limited utility. To provide coverage around an accelerator, other types of units must be considered.

One other means of mobility or transportation around an accelerator is the use of overhead cranes. Normal overhead cranes would need major modification to make them suitable for manipulator use. Their use for general lifting and moving would be practically eliminated. As an alternate, the wall mounted boom support is suggested, Fig. 14. This wall mounted rig will accept an electrically operated manipulator. The operator with the aid of televisions and other remote viewing means can be located in a low activity area or even in a remote control room. The possible coverage with this kind of a support system is much greater than that possible by other means, as is evident in the figure. A wall mounted support system of this type, although shown as an articulating boom, can be made in the form of telescoping members, pantograph arrangement or even a fixed boom with a trolley support. The wall mounted boom arrangement being a secondary overhead transport system can be tailored for manipulator use and will not encroach upon the heavy general purpose overhead cranes. As a matter of fact, the large cranes being totally independent of the manipulator can be used in conjunction with the remote handling equipment to lift and steady large objects.

In cases where close direct viewing or emergency repairs may be required, a hook supported, shielded cab manipulator is contemplated, Fig. 15. General use of this device is not being considered because it relies on an overhead crane for its mobility.

Indirect Viewing

With the proposed remote handling means, the operator is located an appreciable distance from the manipulator. This, as mentioned before, requires remote viewing apparatus which denotes, in general, closed loop television systems. Stereo or multicamera viewing is required to perform a task because of the limited field of vision of one camera. In doing close work, we show two cameras mounted on the manipulator structure. These two cameras are required for depth perception. Colored television, if available, could be used to a great advantage, especially if parts of the accelerator were color coded. Over-all viewing for positions of cranes, manipulators and the like should be provided by an independent system. Cameras associated with this system should be permanently mounted at strategic locations near the ceiling.

Cranes

General purpose overhead cranes should include features that permit their operation from remote locations. Hooks must have good rotational coupling with the load being lifted and be power rotated for positioning. Transducers and readout will be used to prevent overloads or damage to equipment. The intelligence required to position and operate the cranes can be done via a trolley and pickup means with the use of tone or pulse modulated controls. Wireless schemes are not favored because of their susceptibility to stray electrical interferences.

During accelerator operation, the cranes should be parked in a low activity zone. The cabs of the cranes must be provided with a nominal amount of shielding to protect the operator from the high background when operated from the bridge location.

Apparatus Removal

Thus far we have discussed the handling equipment and its application. The over-all scheme includes the removal of highly activated components of the accelerator out of the building housing the machine. Equipment extracted by the cranes and manipulators will be removed from the building by means of a lead-lined transport car. This car, in turn, will be moved to an outside storage area or a hot storage facility. Removal of the hot apparatus out of the accelerator, in many cases, will reduce the ambient condition at the accelerator for a more direct approach during repairs.

Shadow Shielding

Further control of the induced activity, especially from localized hot spots or areas, can be accomplished by shadow shielding. A nominal amount of steel or lead can be placed at the highly activated area to keep the shine to a minimum at the low dose regions. This shielding can be stored on the floor in the nearest low activity area during the time the machine is operated. When access to the machine is necessary, the shield can be lifted by the crane and placed near the offending object or area. In many instances, the removal of hot items and the use of shadow shields will provide normal controlled access in making repairs by conventional means.

Acknowledgments

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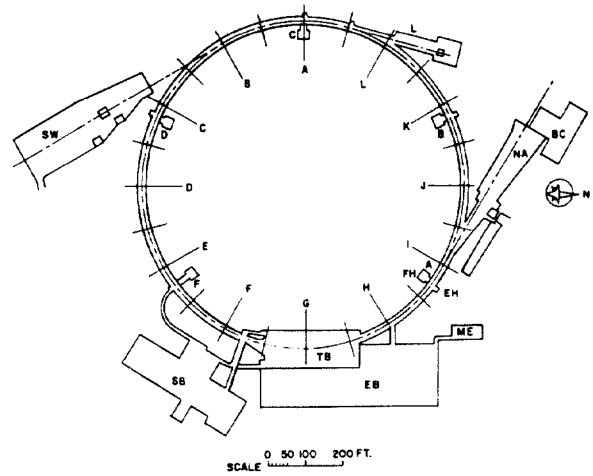


Fig. 1. Physical Layout of Brookhaven Alternating Gradient Synchrotron.

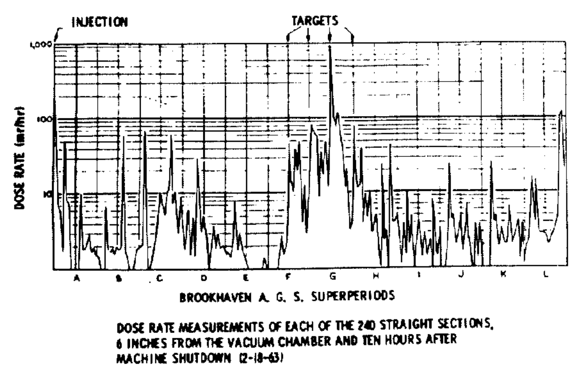


Fig. 2. Dose Rate Measurements - Brookhaven AGS Superperiods.

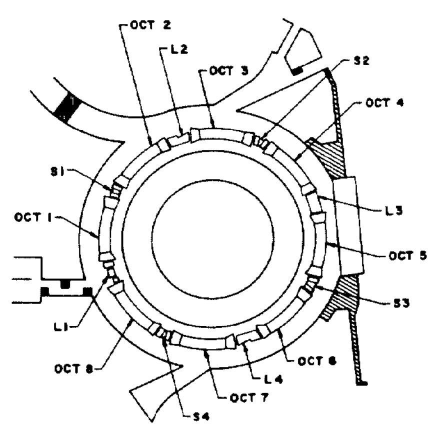
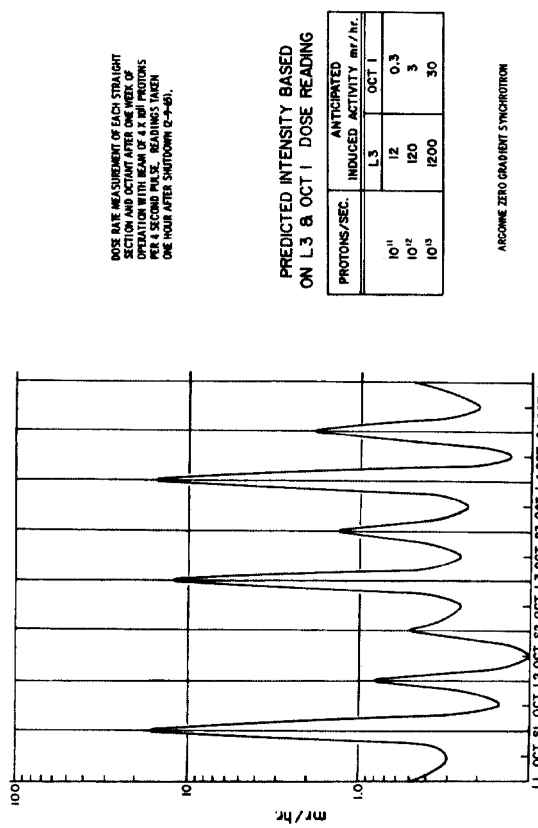


Fig. 3. Physical Layout of Argonne Zero Gradient Synchrotron.



PROTONS/SEC.	ANTICIPATED INDUCED ACTIVITY mr/hr. L3	OCT 1
10^{11}	12	0.3
10^{12}	120	3
10^{13}	1200	30

Fig. 4. Dose Rate Measurement - Argonne National Laboratory.

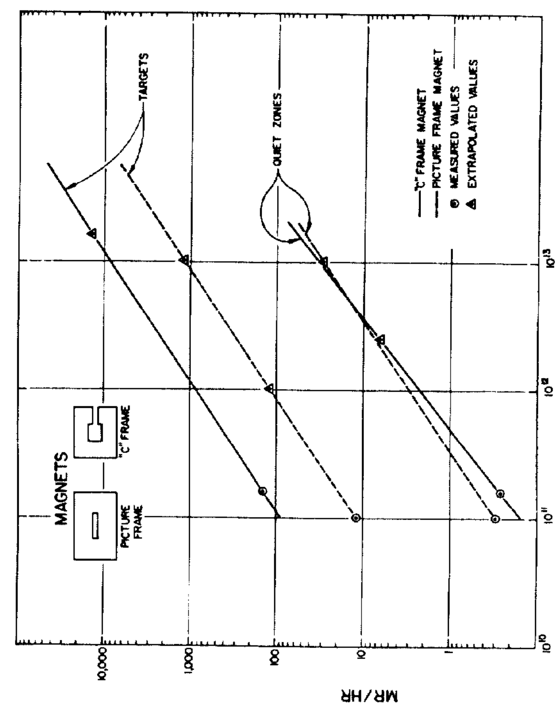


Fig. 5. Induced Activity Trends.

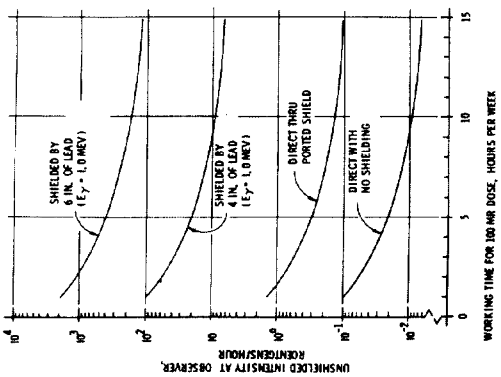


Fig. 6. Modes of Operation for Various Radiation Intensities.

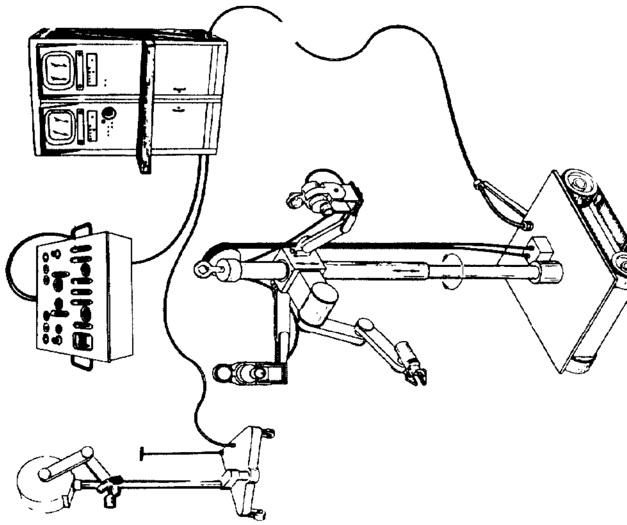


Fig. 7. Switch-Operated Remote Handling Manipulator.

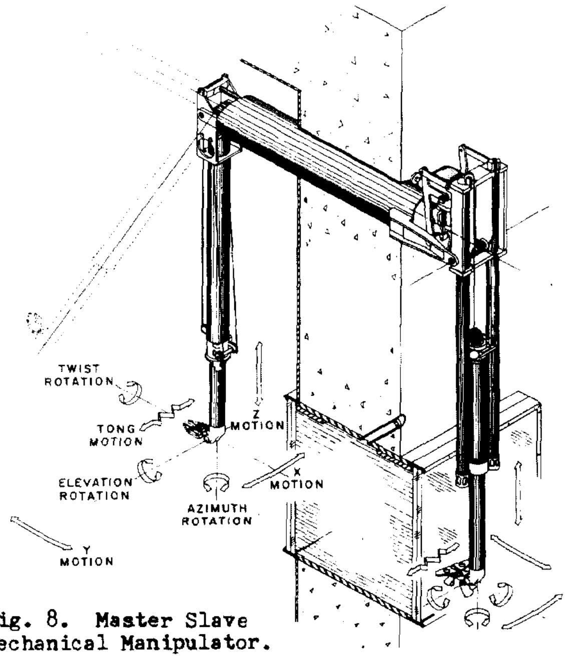


Fig. 8. Master Slave Mechanical Manipulator.

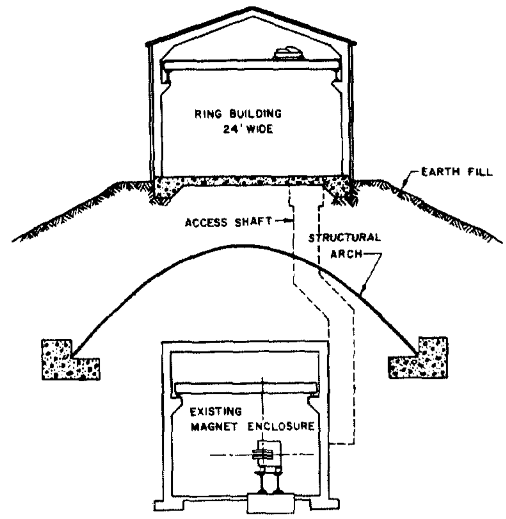


Fig. 9. Typical Cross-Section - Brookhaven Alternating Gradient Synchrotron.

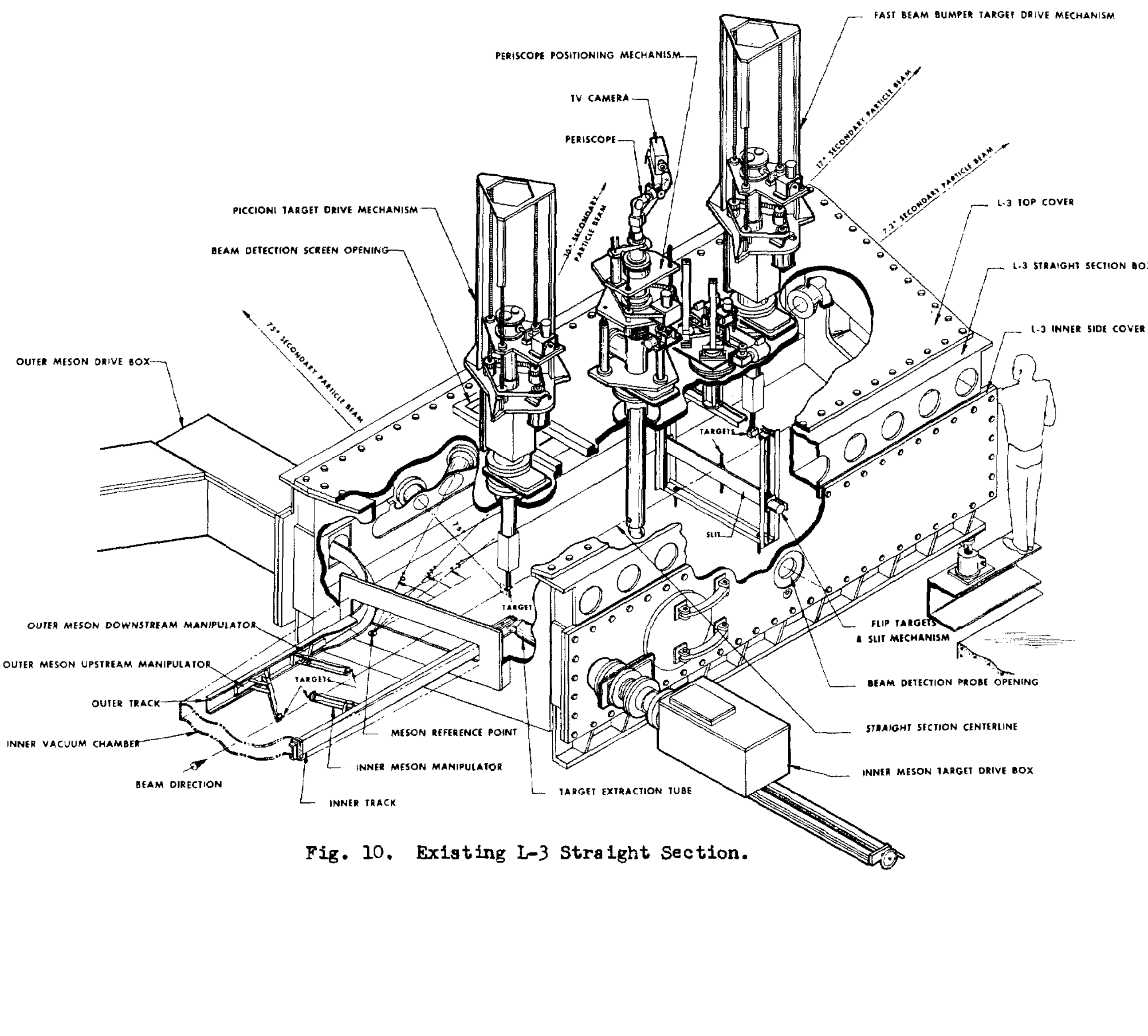


Fig. 10. Existing L-3 Straight Section.

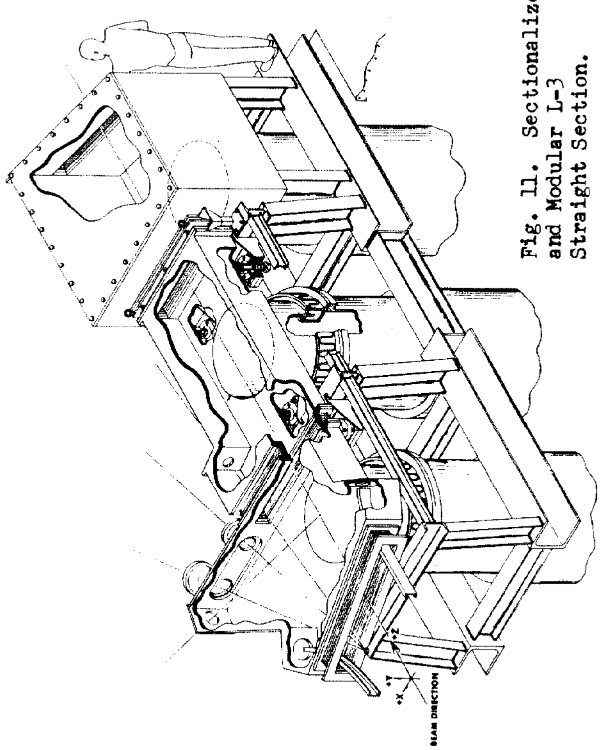


Fig. 11. Sectionalized and Modular L-3 Straight Section.

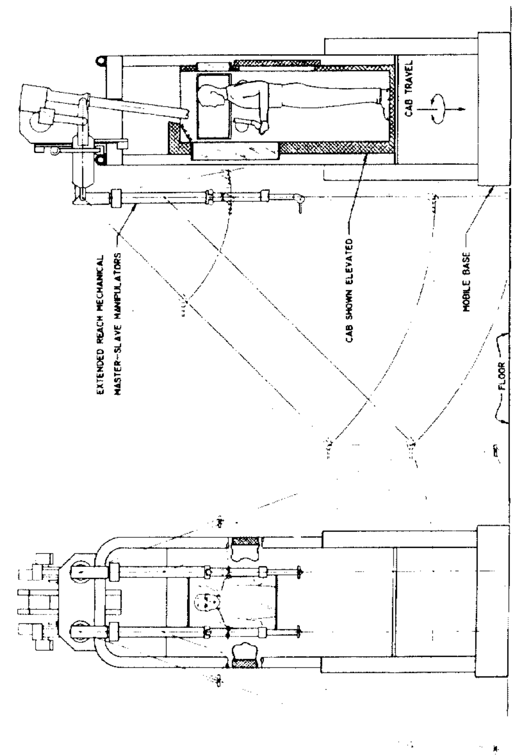


Fig. 12. Mobile Shielding Cab with Manipulators.

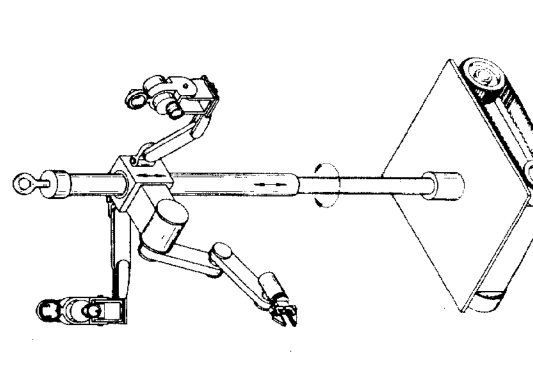


Fig. 13. Robot Vehicle.

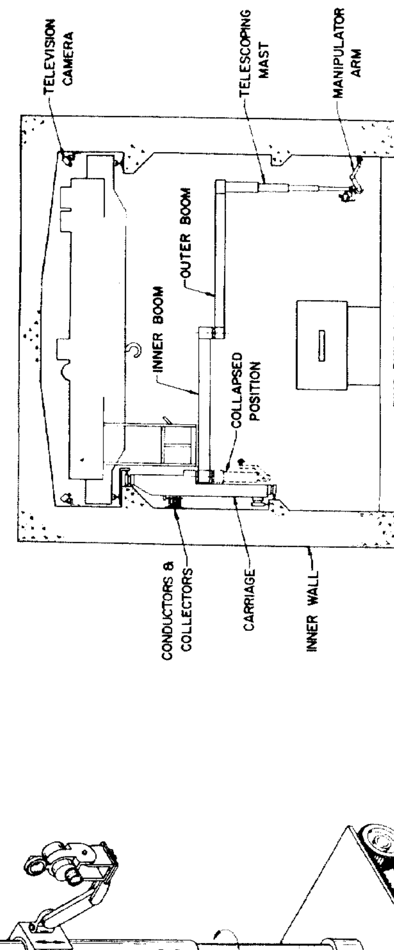


Fig. 14. Wall Mounted Boom System.

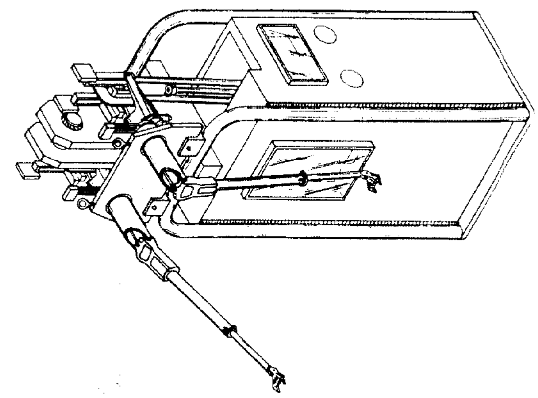


Fig. 15. Crane Supported Shielded Cab with Manipulator.