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DOCUMENT NO.

HW-59449

SERIES AND COPY NO.

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March 4, 1959

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SCOPE REPORT,
DISCHARGE AREA REMOTE MANIPULATOR

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SCOPE REPORT,
DISCHARGE AREA REMOTE MANIPULATOR

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SCOPE REPORT,
DISCHARGE AREA REMOTE MANIPULATOR

I. INTRODUCTION

Trends in IPD reactor operation and maintenance have created the need for a rear face Hanford reactor manipulator which can routinely perform certain maintenance and operational functions, and which under high radiation exposure conditions can permit ruptured slug removal or other emergency type operations to be conducted with little or no personnel radiation exposure. The trends necessitating this development program are as follows:

1. The conflicting conditions caused by: 1) the desire to reduce personnel exposure to a minimum, and 2) the availability of people necessitates that as many burn-out jobs as possible be accomplished by remotely operated mechanical devices.
2. Higher reactor power levels have aggravated the stuck slug rupture problems and, on occasion, removal operations cannot be done quickly due to the lack of available exposure time.
3. Any projected decrease in allowable radiation exposure will require a significant addition of personnel unless means are found to accomplish high exposure jobs with mechanical devices.

Until mechanical devices are developed which can routinely perform functions in the high exposure rear face work area, significant reductions in maintenance personnel cannot be considered even if factors other than available radiation exposure would permit. With the existing conditions, any serious mishap such as a very bad rupture or entlodgment of slugs in the rear face piping could cause a very serious situation in IPD, due to the effect of such a situation on the bank of available personnel exposure, and desirable maintenance programs would have to be deferred.

The manipulator development program in industry has a history of about 10 years. To a large degree, the initial programs were devoted to the development of equipment which would permit remote operation of hot cells in radiation laboratories. The more recent trends in manipulator development have been directed towards provision of tools which would perform specific critical maintenance functions in support of new development work, as in the aircraft nuclear reactor field. At Hanford, where the reactors were designed to be serviced by hand tools, the problem involved in the development of a satisfactory manipulator program is one of recognizing those specific rear face operational functions which are costly from personnel exposure conditions, yet which are capable of being performed by specialized remotely operated manipulator tools.

Because of the need for several tools, it was decided that the most desirable approach to a satisfactory manipulator program would be to provide a multi-tool manipulator which could do several distinct tasks. Of these tasks, removing the rear face nozzle caps to facilitate removal of ruptured slugs and performance of ruptured slug removal operation were the most profitable routine functions which could be accomplished by

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a manipulator. The conventional mechanical arm was considered for use in non-routine situations such as recovery of slugs lodged in rear face piping or other disaster type situations which on occasions do happen.

To insure the quickest return on the economic benefits of the program, the cap remover development was conducted as a separate study since it is more definitive than the remainder of the manipulator program. A second phase involving the application of the mechanical arm and development of specialized tools was initiated with the General Mills Company to capitalize on their progress in the field.

This report evaluates the progress of the second phase of the manipulator development program.

SUMMARY AND CONCLUSIONS

A development study to provide a reactor discharge area manipulator has been in progress for approximately two years. The program was initiated as a means of reducing the radiation exposure to which maintenance and operating personnel are subjected while working adjacent to the reactor discharge face.

The design criterion has been resolved for a machine which will be mounted in the reactor discharge area and perform a majority of the high radiation burn-out functions. The basic machine has been preliminary developed by General Mills, Inc., working under Development Contract DDR-42. The auxiliary portions of the machine scheduled for Hanford development are scoped and in various stages of development.

General Mills, Inc., as part of their obligation under the Development Contract has submitted specifications, drawings and a Proposal Report outlining their detailed plan of attack to provide the required machine. They are confident of the feasibility of the planned approach and of the ultimate success of the outlined program.

FUNCTIONAL REQUIREMENTS

The machine, as presently planned, will consist of a remotely controlled carriage riding on rails laid on the bottom flanges of the discharge area elevator I-beams. The carriage will carry a set of interchangeable devices which will perform the required maintenance and operating functions under the control of an operator remotely stationed at an operating control console.

To successfully mechanize the discharge area functions, the machines proposed for mounting therein must meet certain basic functional requirements:

1. The machine must be capable of doing the work normally encountered in the discharge area, such as removing nozzles, caps, pigtails and gunbarrels and replacing them if possible, slugs should be retrievable from anywhere in the effluent piping array, crossheader valves should be manipulated, and ruptured slug removal equipment should be manipulatable. Some of these functions, such as stuck ruptured slug removal operations need not be done as rapidly as by manual means because they are non-routine and some lost time here has no profound effect on operating efficiency, but operations such as cap removal for ruptured slug discharge should be done rapidly, because these operations have a considerable affect on reactor operating efficiency.

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2. No operation performed must jeopardize reactor safety in any respect, i.e., the machine must be provided with interlocking safeguards so it cannot be caused to move unless all portions are clear of the reactor piping to prevent injury to the reactor.
3. The reactor must be provided with an easily read three dimensional coordinate readout system so the working portions of the machine may be placed with certainty to any required position in the discharge area. This portion of the machine should be designed so the transistion to complete automation of the installation can be done with a minimum of additional work.
4. The machine should be simple to maintain and utterly reliable in operation.
5. The removal of the machine from the discharge area should be simple, so routine maintenance and periodic inspection can be done with a minimum of difficulty.
6. The machine should be simple in operation so the performance of routine tasks can be done by regular pile operators without specialized training or aptitudes in operating remotely controlled equipment.
7. Future interlocking of the machine into the reactor safety circuits should be considered so it can be adapted to operational charge-discharge with a minimum of additional work.

The basic philosophy used in developing and designing this equipment has been to stress simplicity, reliability, and ruggedness. Past experience has shown that no matter how good a tool may be, it will not be accepted as an operating auxiliary if it is difficult to operate or maintain.

DESCRIPTION OF THE PROPOSED MACHINE

As Figure 1 shows, the presently proposed machine mounts under the discharge area elevator. As shown, the installation consists of a carriage movable along the elevator because of flanged wheels riding on rails laid on the bottom flange of the elevator I-beams. The carriage is driven on the track, across the face of the reactor, by motor driven geared wheels engaging gear racks laid down adjacent to the rails. On the carriage are ways in which a platform can move transversely to the elevator, in and out in relation to the reactor. Carried on the platform are a cap remover⁽¹⁾ with a discharge trajectory guide, a General Mills type mechanical arm and a station on which readily interchangeable tools can be mounted. These interchangeable tools may be a rib remover, a guillotine, a high pressure water spray for decontamination or any other special tool which might be developed for a specific job. The platform is supported by a pivot bearing at the rear and a worm gear driven link at the front so a fine vertical adjustment can be had by raising and lowering the link through the worm gear, which is motor driven. This mounting results in a machine which is coarsely (within plus or minus 1 inch) located vertically by the vertical drive on the elevator, finely located vertically to plus or minus 1/16 inch by the pivot link, and finely located horizontally to plus or minus 1/16 inch by the motor driven gears engaging the racks on the elevator I-beams. The machine is also provided with a traverse platform drive which moves the tools in and out in relation to the reactor.

(1) HW-57579 - "Reference Material for Cap Remover Proposals."

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The position of the machine is at all times monitored by means of a selysen type readout system which gives the position of any part of the machine to plus or minus 1/16 inch. A differential selysen is utilized to compensate for inaccuracies in the vertical travel of the elevator in its vertical guide ways.

The machine is provided with two television cameras, as shown in Figure 2, which permit visual monitoring of all machine activities on a television receiver located at the operators control station. The television cameras may be used as auxiliary aligning devices, because the cameras are located at an integral number of lattice spacings from the machine tools, so if the camera is located on a nozzle by means of an aiming reticule in the lens, the machine is automatically in position.

The machine is very readily removable from the elevator into a tool dolly room. The tool dolly room will in all cases be as the C, H, and K tool dolly rooms, and will be provided on reactors not now so equipped. To remove the machine from the elevator, the elevator is located at the tool dolly room, the dolly room door to the discharge area is opened and the machine is run into the dolly room across a bridge spanning the gap between the elevator rails and similar rails in the dolly room. The transfer from elevator to dolly room will in the final installation design be done remotely, and may be accomplished during reactor operation. It is planned to provide spare parts so if mal-function makes a machine inoperable, it can be run into the dolly room for rapid servicing and repair. This is to assure almost absolute continuity of machine coverage in the discharge area.

General Mills, as part of their development package, has designed a special dolly which will ride on the elevator I-beams and greatly aid in the original installation of the rails on the beams. This dolly is shown in Figure 3. This dolly can be considered as a movable scaffold which will permit several men to work underneath the elevator during installation of the rails. The dolly is designed to ride along the elevator, over the machine, so in the unlikely event that the machine fails so it cannot be powered off the elevator, the dolly can be placed on the elevator, run out to the machine with several men aboard, who will there repair the machine so it can be removed.

REMOTE MANIPULATOR DEVELOPMENT PROGRESS

As the attachments to this document show, the proposed installation development is fairly complete. General Mills has completed their preliminary development package and have submitted preliminary design drawings, specifications, and a proposal report (attached.)

The package which General Mills proposes to supply will consist of the basic carriage, with a heavy duty mechanical arm mounted in the center tool station. The package will also provide the elevator rails and all appurtenances required to mount the rails to the elevator I-beams, a dolly for transferring the machine from the elevator to the tool dolly room and vice versa (this is not a remote removal tractor such as will be ultimately developed,) and a remote operational console.

Auxiliary equipment scheduled for Hanford development and its present status is as follows:

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A. Cap Remover

The cap remover mechanism as described in HW-57579, "Reference Material for Cap Remover Proposal," will be perfectly compatible with General Mills Remote Manipulator and it will mount on one of the two outer tool stations provided. The "K" area cap remover design will be altered as required to fit other reactors and will be used as developed on all subsequent manipulator installations.

B. Rib Remover Tool

The rib remover tool is required to aid in the removal of stuck ruptured slugs by cutting away the major portion of the process tube ribs on the downstream side of the rupture. This will permit the easy discharge of a ruptured swollen or warped slug because of the added annular clearance around the slug.

As presently conceived, the rib removing tool will consist of a pair of cutters rotating on axes parallel to the longitudinal axis of the process tube. The cutters will be driven by means of a 30 ft. long flexible shaft, in turn driven by an air motor mounted on the manipulator. The cable drive motor and a set of powered rollers for driving the flexible cable into the tube will be carried on one of the tool stations on the manipulator carriage.

This tool is now undergoing development. The cutters, flexible cable, drive and driven rollers are in various stages of completion. This tool should be available for pile testing by May 1, 1959.

C. Process Tube Removal Guillotine

A part of the process tube removal operation is the cutting into short lengths of the old process tube, making possible its removal from the discharge area. The tube must be cut into lengths because the discharge area is too narrow, about 12 feet, to permit the entire tube to be pushed out of the reactor. In practice, the tube is eventually cut into about 1 foot lengths to make disposal easier. The actual disposal process is made difficult by the relatively high radiation reading characteristics of the film deposits on the inside of the old tubes.

A device is now being developed which will pull the old split process tube from the reactor, chop it into 6 to 12 inch long lengths and package them into a bag similar to a mail bag for easy disposal.

A prototype tube guillotine such as described has been fabricated and is presently being debugged. When the manipulator carriage is available, this tool will be mounted on one of the tool stations.

This device should be ready for preliminary on-pile testing about April 1, 1959.

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Mechanical Arm

The mechanical arm which is part of the General Mills package will be the means by which the unplanned for, unpredictable event is cared for. The mechanical arm will be a heavy duty type, able to withstand immersion or sluicing by 100° centrigade water. The arm's analogous shoulder will rotate 360° at 3 rpm and exert 200 lb.-ft. of torque force, the shoulder will be capable of lifting 100 lbs. with the hand upper arm and forearm horizontal, 240 lb. with the hand and upper arm horizontal and forearm vertical, and 2,000 lb. with the hand (using a hook) upper arm and forearm vertical. The wrist will exert 60 lb.-ft. at 8 rpm, 360° rotation, and the hand or hook will exert a 280 lb. closing force.

The mechanical arm is designed so auxiliary tools such as cutters, drill motor or saw can be plugged into the hand socket, so functions entailing these operations can be done remotely.

Tasks planned for the mechanical arm are cutting of pigtail and nozzle removal of badly contaminated rupture tubes, retrieving of irradiated slugs lodged in the discharge area piping array, and back seating of ruptured slugs preparatory to rib removing operations. There are other jobs which developmental work may prove are feasible of being done by the mechanical arm. These may be thermocouple reseating, rear face decontamination, or valving for example.

PROCUREMENT AND INSTALLATION

It is hoped that the procurement and installation of this device can proceed in a calm orderly manner, so the best possible equipment will evolve to assure that this very important area is adequately serviced. The schedule of procurement and installation is planned as follows:

A. Scoping and Preliminary Development

This phase is completed with the recently finished General Mills Design and Development contract.

B. Final Design

This will be the subject, with procurement, of the next contract, preferably with General Mills for the acquisition of a prototype device. The contract will be initiated upon approval of the project proposal requesting funds for the design and procurement of a prototype machine.

C. Procurement and Testing of a Prototype Manipulator

The objective of the initial project proposal is the purchase of a prototype device for installation in the 108-D Building flow laboratory. Testing, evaluation, auxiliary tool development and debugging will be carried out in this location, using Process Technology funds. Prior to reactor installation, an operator and maintenance education and training programs will be instituted to assure a pool of skilled operators for the equipment when it is finally installed.

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D. Reactor Installation of Prototype

When the prototype machine is deemed satisfactory, it will be installed on a reactor for actual on-pile testing, evaluating and testing.

E. Final Installation

The final phase of this developmental program will require the equipping of all reactors, where economically justifiable, with remotely controlled manipulators. This phase will extend beyond 1961, and will mark the completion of the program.

ATTACHMENTS

Figure 1 - Rear Face Manipulator.

Figure 2 - T.V. Camera Coverage

Figure 3 - Installation Dolly.

Copy, General Mills Inc., Proposal 8-3012, "Detail Design, Fabrication and Testing of a Prototype Under-Elevator Mounted Rear Face Manipulator."

Copy, General Mills Inc., "Specification for a Prototype Under-Elevator Mounted Rear Face Manipulator."

II. ORDER OF MAGNITUDE JUSTIFICATION FOR REACTOR DISCHARGE AREA REMOTE MANIPULATORS

The project proposal presently being prepared for the procurement of a Remotely Controlled Discharge Area Manipulator asks only that funds be made available for a prototype machine which will be initially used as a laboratory tool for evaluation, development and training. The balance of the planned overall program, for which one or more project proposals will be issued at some future date, will entail the installation of the first manipulator on a reactor and the procurement and installation of manipulator machines on several, or all reactors, if this step is justifiable from an economic and radiation reduction standpoint. Therefore, to establish the need for a prototype machine, as well as to scope the future project, this justification will be developed in part as though the manipulator was scheduled for immediate installation on a reactor.

There are several significant areas of benefit from the acquisition of Remote Manipulators for use on the Hanford reactors. These benefits are:

A. Discharge Operations Benefits

Economic return from invested capital in the form of increased reactor operating time, resulting in increased production. This particular benefit facet will result primarily from the use of the cap remover for rupture slug removal or for metal discharge during the cooling off period. It has been shown (1) that the benefits derivable from the installation of cap removers on the "K" Reactors will approximate \$860,000/year for the two "K" Reactors. It is safe to assume that the slug rupture rate in the old reactors will be about the same as in the "K" Reactors, and that the total production rate in the old reactors will be approximately one-half of the Hanford total production. From this formula, we may deduce that the savings on each old reactor attributable to the cap remover function will approximate \$145,000 per year.

$\$860,000 \times 1/6 = \$145,000$ per year per old reactor

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B. Reduction in Personnel Exposure Benefits

The major benefit from remote manipulators use will accrue from the reduction in personnel radiation exposure. The total radiation exposure received in IPD has shown a consistent upward trend over the past several years. The attached Figure 4, prepared by Radiological Engineers of IPD, Research and Engineering Operation, graphically depicts this trend from 1953 to 1958, and extrapolates to 1960. As can be seen, the 1960 extrapolated levels will represent a 2 to 3 time increase over the 1953 figures. What is more disturbing is the rate of increase of all curves during the more recent years. This is probably caused by greater maintenance requirements on aging equipment as well as by accumulation of radioactive products in process piping.

The use of Turco or any other descaling mechanism for lowering the background in the discharge area will have little effect on the area of activity for which the manipulator is designed, except for making the original installation simpler and cheaper. Turco will be of no benefit in reducing the radiation from a lost slug, it will not greatly affect the background from a severe rupture, and of course entry into the rear area for flush discharging of slugs is prohibited because of the radiation from the slugs, as well as the hazard in entering the area during the times when water pressure is high, as is the case when flush discharging. Turco can, however, make a great difference in the time and cost of installing the manipulator in the discharge area. It is hoped that the major portion of the installation work can be done at levels of approximately 10 mr per hour by locating the elevator at its upper limit of travel and decontaminating the effluent piping by Turco flushing prior to doing this work.

C. Detailed Discussion of Reduction in Personnel Exposure Benefits

Historically, the size of the work force in IPD has been governed by the amount of work to be done, and not by the necessity of keeping employees within the established annual exposure limits. IPD experience has also been one of continued production increases and associated with these production increases has been an increase in the total radiation exposure of exposure used. Production increases are planned for the future and it is reasonable to expect that maintenance work will increase as the reactors become older. Therefore, we expect increased radiation dose rates around the reactors and an increase in the amount of radiation work associated with reactor operation.

Figure 4 illustrates the exposure experience of the Radiation Monitors, Processing Operators and Mechanical Maintenance Craftsmen over the years. All marked points are actual gamma exposure received from film badge results. A reasonable estimate of future radiation exposure can be made by extrapolation of this information. From this extrapolation, an estimate of the average annual dose per man can be calculated. The results of such calculations are included in Table I as follows:

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TABLE I

<u>Group</u>	<u>1958</u>		<u>1959</u>		<u>1960</u>		<u>1961</u>	
	<u>Total</u> <u>for</u> <u>Group</u>	<u>Average</u> <u>per</u> <u>Man</u>	<u>Total</u> <u>for</u> <u>Group</u>	<u>Average</u> <u>per</u> <u>Man</u>	<u>Total</u> <u>for</u> <u>Group</u>	<u>Average</u> <u>per</u> <u>Man</u>	<u>Total</u> <u>for</u> <u>Group</u>	<u>Average</u> <u>per</u> <u>Man</u>
Radiation Monitors (81 men)	240 r	3,000 mr	275 r	3,400 mr				
Mech. Maint. (167 men)	322 r	1,930 mr	400 r	2,400 mr	480 r	2,900 mr		
Processing Operators (264 men)	515 r	1,950 mr	575 r	2,200 mr	640 r	2,400 mr	About 2,900 mr	

There are several different annual limits in effect at HAP0. Each limit applies to a specific type of radiation and a particular organ or part of the body. Of course, the exposure of each individual must be within all of these limits. The whole body gamma limit of 3r per year has always been the limiting factor in the exposure of IPD personnel. It can be seen from Table I that IPD has a serious exposure problem with the Radiation Monitoring personnel in 1958. This problem is expected to be even more serious in 1959 unless exposure reduction programs are successful. In 1959, the radiation exposure of Mechanical Maintenance personnel will be high enough that considerable scheduling and transferring for exposure distribution purposes will be necessary and a serious exposure shortage will exist for this group in 1960. Processing operators will also follow this trend with exposure distribution problems apparent in 1960 and serious shortages in 1961.

The General Electric Company is resolutely committed to a 3r/year radiation limit for personnel; because of job and radiation control coordination difficulties, the practical limit is probably about 2.75 r/year. From the presented curves in Figure 4, it is obvious that it will be impossible to stay within the limits with the present work methods and in the present radiation background levels. Decontamination with Turco will undoubtedly reduce these figures for the routine work, but it will not have too much influence for the out of ordinary incidents which come up. It is in these latter happenings where radiation control measures are apt to fail and the hazard of an overexposure exists. It is in the field of the non-routine high radiation job that the manipulator is designed to work.

The proposed remote manipulator will be capable of a variety of maintenance and production tasks, and can perform many of these tasks without personnel entry into the radiation zone. From records of past exposure experience, an estimate of the radiation exposure which the equipment will save each work group can be made. These estimates were made, assuming that the original installation would be made in 105-H, and assuming the following utilization of the manipulator.

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1. Survey for Ruptures and Quickie Discharge - The manipulator will perform all phases of this work without personnel entry to the discharge area.
2. Charge-Discharge - The manipulator may eventually do all discharge area operations and eliminate personnel entry during this work.
3. Stuck Rupture Removal - The manipulator is capable of all phases of this operation except actual tube removal and replacement. The manipulator can remove and replace nozzles and pigtails, backseat stuck charges, and remove ribs from tubes.
4. Tube Replacement - While the manipulator is capable of performing several of the steps in this operation in the beginning, it probably will be used only on problem tubes and rupture tubes where abnormally high dose rates exist around the tubes.

Using these assumptions and using 1958 exposure experiences, the following estimated annual exposure savings could be realized with a manipulator installed in one reactor.

TABLE II

ESTIMATED EXPOSURE SAVINGS WITH MANIPULATORS
(Discharge Area Exposure Only)

JOB	Estimate of Exposure used in 1958 mr			Estimate of Exposure used if Mani- pulator were in service mr			Exposure Reduction mr		
	<u>R.M.</u>	<u>Maint.</u>	<u>Process</u>	<u>R.M.</u>	<u>Maint.</u>	<u>Process</u>	<u>R.M.</u>	<u>Maint.</u>	<u>Process</u>
Rupture Surveys and Quickies	800	0	3,600	0	0	0	800	0	3,600
Charge- Discharge	4,300	0	11,000	0	0	0	4,300	0	11,000
Stuck Rupture Remv.	2,100	6,900	3,000	1,100	2,200	2,100	1,000	4,700	900
Tube Replac- ment	4,300	10,300	3,300	3,900	9,300	3,000	400	1,000	300
TOTALS	11,500	17,200	20,900	5,000	11,500	5,100	6,500	5,700	15,800
TOTAL REDUCTION							28,000 mr		

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The total estimated exposure reduction of 28,000 mr represents about 24% of the total radiation exposure used by the three groups in 100-H Area. Radiation Monitors' exposure would be reduced by about 23%, Maintenance exposure would be reduced by about 17%, and Processing exposure would be reduced by about 29%. The exposure reduction which would be realized if the installation were made in another reactor may be different because of different dose rates in the discharge area and varying amounts of charge discharge, rupture work, and tube replacement. It is interesting to note that the estimated annual exposure reduction at this one reactor represent the usable annual exposure of 3 Radiation Monitors, 2 Maintenance Craftsmen, and 6 Processing Operators for a total of 11 men. These numbers may be multiplied by eight to obtain a rough estimate of the exposure reduction possible with a manipulator in each discharge area.

It appears that another advantage may be gained by the installation of these manipulators. The eight technical over-exposures which occurred in IPD during the period January through September 1958, were reviewed. Four of these occurred in the discharge areas during work which could be done by the manipulator. It appears that use of the manipulators in IPD would reduce the number of technical over-exposures by reducing the exposure of employees to very high dose rates and to concentrations of high level contamination.

In addition to the foregoing, there are certain intangible advantages to be gained by reducing radiation exposure. Because of the lack of information and knowledge on long term genetic and biological effects of exposure to radiation, all national and international groups which have radiation control responsibilities repeatedly recommend that, while definite numerical limits are established, it is still the best policy to limit the total exposure of personnel to the lowest practical level. In addition to compliance with these recommendations, lowering total exposure places the company in a more advantageous position in the event that annual limits are lowered at some future date.

TECHNOLOGICAL BENEFITS OF A PROTOTYPE LABORATORY MANIPULATOR

The proposed manipulator is scheduled for initial mounting in the 108-D Building rear face mock-up. In this location, a period of about six months will be devoted to testing and evaluation of the General Mills supplied equipment, to developmental work on the Hanford designed auxiliaries, and to training of the maintenance and operating work forces. In this way, the evolved machine will have demonstrable ability to do its assigned functions, its operating and maintaining work force will be familiar with its limitations and requirements, and lastly, a great deal of engineering background on remote mechanization will necessarily result from this program.

SUMMARY OF BENEFITS

It is hoped that it has been shown that the acquisition of this prototype manipulator is an important initial step in a well integrated program to reduce personnel exposure to radiation at Hanford. In summary, the program has and should proceed as follows:

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SUMMARY OF BENEFITS (Continued)

- A. Scope and preliminary develop the required equipment to meet the established need. This has been done by liaison between Hanford and General Mills. The culmination of this phase has resulted in the now available General Mills proposal (attached.)
- B. Final design and prototype procurement, the current phase of the overall program.
- C. Laboratory testing, evaluation, development and training, the proposed next step contingent upon the approval of the prototype project proposal.
- D. Reactor testing and evaluation of the prototype machine.
- E. The successful conclusion of the preceding step will call for the equipping of all reactors with manipulators, the subject of future project proposals.

III. ORDER OF MAGNITUDE COST OF THE REMOTE MANIPULATOR

The following order of magnitude cost estimate for remote-manipulator was developed by representatives of Equipment Development, Project Engineering, and Estimating. It is a best estimate using preliminary design drawings, limited scope and in the face of changing conditions, in the reactor radiation situation. The estimate must be used with the caution attending the use of all preliminary estimates.

COMPARISON CHART - MANIPULATOR INSTALLATION

	<u>K</u>	<u>C-H</u>	<u>B-D-DR-F</u>
Installation Cost Per Reactor	\$500,000	\$500,000	\$550,000
Installation Cost Equivalent Operating Days/Reactor	5	13	17
Days Downtime For Installation/ Reactor	3	3	4*
<hr/>			
Total Installation Cost - In Equivalent Days/Reactor	8	16	21

* Additional time required to install tool dolly room.

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COMPARISON CHART - MANIPULATOR SAVINGS/YEAR

	<u>K</u>	<u>C-H</u>	<u>B-D-DR-F</u>
Quickie Discharge of Ruptured Slug - One every two months - Operating Days Saved Per Year	6	6	6
Discharging during Cooling-Off Period. Days Saved Per Year	4	4	4
Removal of 1 Stuck Ruptured Slug/Year - With Rib Removing Tool - Operating Days Saved Per Year	2	2	2
Recovery from One Extraordinary Incident/Year, such as a slug log in the pigtails, etc., - Operating Days Saved Per Year	1	1	1
TOTAL DAYS SAVED PER YEAR PER REACTOR	13	13	13

	<u>K</u>	<u>C-H</u>	<u>B-D-DR-F</u>
Payoff Period According to this Comparison/Reactor	8/13 = 0.615 years	16/13 = 1.23 years	1.61 years

No credit has been claimed here for savings which might result from using the manipulator in process tube removal work, from thermocouple repair, bellows work or inspection of rear face conditions.

ORDER OF MAGNITUDE COST ESTIMATE
ONE PROTOTYPE REMOTE MANIPULATOR

<u>Description</u>	<u>Labor</u>	<u>Material</u>	<u>Equip. Usage</u>	<u>Total</u>
Manipulator as received from General Mills - Carriage, Mechanical Arm, Console, etc.				\$175,000
Cap Remover Head	\$2,500	\$3,000		5,500
Installation in 108-D	3,000	2,000	\$2,000	7,000
Contingencies				12,500
			TOTAL	\$200,000

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Fig. 4
GAMMA EXPOSURE TREND IN I.P.D.
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FIGURE 1

REAR FACE MANIPULATOR & REMOTE CONTROLLED CAP REMOVER-UNDER ELEVATOR MOUNT-REVISED

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FIGURE 2

T.V. CAMERA COVERAGE

REAR FACE MANIPULATOR AND REMOTE CONTROLLED CAP REMOVER

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FIGURE 3

INSTALLATION DOLLY-REAR FACE MANIPULATOR

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19 September 1958

SPECIFICATIONS FOR A
PROTOTYPE UNDER-ELEVATOR MOUNTED
REAR-FACE MANIPULATOR

Prepared for
GENERAL ELECTRIC COMPANY
Hanford Atomic Products Operation
Richland, Washington

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1. INTRODUCTION

The following specifications have been developed as a combined result of 1) Rear-Face Manipulator requirements originally set forth under the terms of Contract DDR-14 for a wall-mounted manipulator and the resulting Summary Report by General Mills, Inc., 2) General Mills, Inc. Proposal 86015 for the design of an elevator-mounted machine, and 3) the present Contract DDR-42 for the layout design of the Under-Elevator Mounted Rear-Face Manipulator Prototype.

2. PERFORMANCE AND OPERATING SPECIFICATIONS

Performance and operating specifications are considered in 2 parts, 1) those functions deemed most necessary to immediate requirements, and 2) future capabilities for more complex operations which can be attempted only after a refined machine has been developed through prototype testing.

2.1 Preliminary Specifications

Specifications for successful machine operation can best be presented by determining performance requirements and then listing the actual operations required.

2.1.1 Performance Requirements

The following specifications must be incorporated in prototype design:

- .1 The complete prototype will be designed and fabricated for mounting beneath a discharge-area elevator with a minimum of assembly work at installation.
- .2 The machine will be designed to be stored in place on the elevator or on a special dolly in the dolly room.
- .3 The machine will carry a General Mills, Inc. submersible heavy duty Mechanical Arm (Model 500, specially altered to permit greater close-range manipulative ability), a Hanford-developed process-tube Cap

Remover, and a spare movable carriage designed to permit the addition of a third special tool at some later date.

- .4 In conjunction with the discharge-area elevator, the machine will be capable of carrying its special maintenance tools to any position in the reactor rear-face tube-and-valve lattice.
- .5 In conjunction with the discharge-area elevator, the system will be capable of remotely and reproducibly locating any of the maintenance tools at a pre-determined lattice center with an accuracy of plus or minus 1/2 inch. A synchro position monitoring system will continuously indicate machine location via a counter which will show the number of the nearest tube.
- .6 The Mechanical Arm will be capable of extending beyond the front flange of the elevator I-beam at least 48 inches. At this extreme reach, the Arm will be capable (with special attachments, if necessary) of picking a slug out of any position in which it might become lodged in the rear-face piping array. The Arm will also be able to manipulate a 3/4-inch bolt-size impact wrench at this reach.
- .7 When fully extended, the Arm will be capable of handling a "gunbarrel" 7 feet long weighing 25 pounds.
- .8 The main carriage drive system will be capable of moving the machine horizontally along the elevator at speeds up to 50 fpm with a 100% duty cycle. The drive will also be capable of exerting a static force of at least 1000 pounds in either direction along its line of motion.
- .9 Coarse vertical positioning of the elevator will be controlled from the console, with accuracies of plus or minus 1/4 inch. (The General Electric Company guarantees the elevator to be locatable to within

plus or minus 1/4 inch.) Elevator position will be ~~continuously~~ monitored by a synchro system similar to that used to locate the bridge. The system will incorporate compensation for elevator end-play.

- .10 Fine vertical positioning will be provided by the movable boom and will be accurate to plus or minus 1/4 inch. Boom position will be combined with elevator position by a synchro monitor system to provide accurate location information.
- .11 The discharge area equipment will be able to withstand a sluicing stream of 100° C water, short-time submersion, and ambient atmospheres ranging from 20° C to 100° C at 100% relative humidity without damaging effects.
- .12 The machine will be constructed on a unitized design basis with all parts easily replaceable in order that maintenance and repair may be performed outside the rear-face area.
- .13 All tools and attachments used by the manipulator will be interchangeable remotely.
- .14 The system will be visually monitored by 3 television cameras. Two cameras will be carried on the machine and the third camera will be mounted to provide an overall cell view.

2.1.2 Operations Required

The prototype Rear-Face Manipulator will be designed to perform the following functions with suitable attachments:

- .1 Locate and remove nozzle caps under reactor operating conditions.
- .2 Locate and remove fuel pieces caught in the rear-face piping array.

- .3 Adjust 4-inch cross-header valves.
- .4 Disassemble nozzles for tube replacement operations; this includes removal of the thermocouple well, pigtail, 4 nozzle-clamping nuts, and actual removal of the nozzle itself. All parts will be retained and transferred to storage bins.

2.2 Future Requirements

In addition to the functions described in the foregoing section, the prototype design effort will recognize the possibility of imposing additional operational requirements on the finally-installed machine. These functions, which are not present operational requirements, follow:

- .1 Nozzle replacement.
- .2 Gunbarrel removal and replacement.
- .3 Nozzle-stud removal and replacement.
- .4 Positioning and operation of VanStone-flange forming and cutting equipment.

Each of these 4 operations is a separate technique and all require more sophisticated manipulation than, say, cap-removal. Thus, it is expected that only after exhaustive prototype testing and "design proving" can methods be developed to perform such functions. Although the design program is immediately concerned with refinement of a basic remotely-operable machine capable of carrying and accurately locating special tools (i.e., a Mechanical Arm and a Cap-Remover), more complex operations are anticipated as techniques and mechanisms evolve through actual testing.

3. SYSTEM SPECIFICATIONS

In addition to the actual performance and operating specifications, general

specifications have been evolved for the system as a whole and the structure of the rear-face manipulator in particular. These requirements became apparent as a result of feasibility studies made to determine the most practical approach to rear-face maintenance equipment. They will be listed briefly since the intent here is to indicate a feasible method without unduly limiting the design.

Development of a workable rear-face manipulator system involves 4 major areas, 1) the rear-face area, 2) the dolly room, 3) the control room, and 4) the electrical equipment room. The system requirements will be listed for each of these areas.

3.1 Rear-Face Area Equipment

.1.1 Rear-Face Manipulator

The Rear-Face Manipulator will execute the actual maintenance operations, guided and located about the reactor rear-face from the control console.

The machine will be comprised of:

.1.1 Main Carriage: basic chassis for the following:

- .1.1 Drive Truck, with pinions to engage racks mounted on rails; this drive will automatically de-clutch if power fails.
- .1.2 Wheel Trucks, to permit machine movement along rails.
- .1.3 Boom, to effect fine vertical adjustments in manipulator carriage location.
- .1.4 Boom-Raise Mechanism, to raise and lower the boom.
- .1.5 Dual-Camera Television Monitoring System, to monitor work area and to serve as auxiliary locating device.
- .1.6 Floodlights, to illuminate work area.
- .1.7 Retractable Stop and Travel Limit Switches, to limit

damaging machine overtravel by both mechanical and electrical means.

.1.2 Manipulator Carriage, to insert and retract the Mechanical Arm and the 2 auxilliary carriages; this carriage will automatically retract if power fails.

.2.1 Mechanical Arm, to effect manipulations requiring unusual dexterity and positioning.

.2.2 Auxilliary Carriages (2), to insert and retract special tools; these carriages will automatically retract if power fails.

.1.3 Manipulator Position Monitoring System, to provide location information for all moving members.

.3.1 Horizontal Position Monitor, to monitor machine travel along the elevator.

.3.2 Fine Vertical Position Monitor, to monitor boom location.

.3.3 Manipulator Carriage Insert-Retract Limit Sensing, to monitor manipulator-carriage travel limits.

.3.4 Auxilliary Carriage Insert-Retract Limit Sensing, to monitor auxilliary-carriage travel limits.

.3.5 "Arm Stored" Sensing, to indicate Arm folded position.

.1.2 Elevator-Attached Equipment

Equipment mounted on the discharge-area elevator to support and aid machine operation includes the following:

.2.1 Rail Assemblies, to permit machine travel along the elevator.

.1.1 Drive Rack, to permit positive driving along the rails.

.1.2 Travel Limit Cams, to prevent damaging overtravel by both electrical and mechanical means at each end of the rails.

.1.3 Elevator-Remote Removal Tractor Alignment Stops, to permit precise alignment of removal tractor with elevator rails when transferring the machine to the dolly room.

.2.2 End-Play Monitor, to correct the monitoring system for unpredictable elevator lateral shift.

.2.3 Multipurpose Cam, to locate elevator position for removal-tractor engagement, to prevent damaging overtravel when machine is over a pad area, and to prevent accidental machine submersion.

.1.3 Wall and Floor Mounted Equipment

Auxilliary equipment mounted on the discharge area wall and floor includes the following:

.3.1 Limit Switches, to locate elevator position for removal-tractor engagement, to prevent damaging overtravel when machine is over a pad area, and to prevent accidental machine submersion.

.3.2 Overall Cell Viewing Television Monitor, to provide an overall view of the machine in operation.

.3.3 Coarse Vertical Position Monitor, to monitor elevator position.

3.2 Dolly Room Equipment

.2.1 Test Station

A test station, located in or near the reactor tool-dolly room, will permit manual control of basic machine movements for test purposes and will allow direct visual checking of machine functions.

.2.2 Remote Removal Tractor

A remotely operable removal tractor, normally housed in the dolly room, will permit automatic machine transfer from elevator to dolly room. The tractor will enter the discharge area on rails from the dolly room, align itself with the rear-face elevator which will be appropriately positioned, allow the Rear-Face Manipulator to drive itself onto the tractor, and will then return itself to the dolly room in an automatic sequence.

.2.3 Trail Cable Assembly

A system of reeled trail cables will feed power and control functions to the machine as it moves about the rear face. The cables will be payed out and reeled up as machine movements demand. This assembly is to be supplied by the General Electric Company.

.2.4 Emergency Retractor Cable Assembly

To provide a means for machine removal from the discharge area in case of power or mechanical failure, a retractor-cable assembly will enable the machine to be pulled off the elevator onto the removal tractor in an emergency. The retractor cable will be payed out and reeled in similarly to the power cables but can also be "power-reeled" if necessary.

3.3 Control Room Equipment

In the reactor control room, a control console will provide the coordinated operator-controls with which the machine will be directed in its maintenance operations. The console will include the T-V receivers and position read-out systems necessary to monitor rear face operations.

3.4 Electrical Equipment Room

In a separate electrical equipment room, the control circuitry required for switching and sequencing machine operations will be housed and arranged to provide easy maintenance and "trouble-shooting." Test-jack panels will be provided to facilitate fast circuit checking.

3.5 Table of Machine Motions, Locations, and Capacities

The following table will provide a summary of machine motions and capacities required for anticipated maintenance operations.

TABLE OF MACHINE MOTIONS, LOCATIONS, AND CAPACITIES*

Motion	Location	Travel	Max. Rate	Capacity
Main Carriage Travel	On rails along the longitudinal axes of the elevator I-beams	50 ft.	50 fpm	1,000 lbs. stall force
Boom Raise	Vertically in a plane perpendicular to reactor face	4 in.	360°/min.	1,000 lbs. net lifting force at tip
Manipulator Carriage Insert/Retract	On rails along the longitudinal axis of the boom	18 in. relative to boom	1 ips	1,000 lbs. stall force
Auxilliary Carriages (2)	On rails along the longitudinal axis of the manipulator carriage	26" relative to manip.car.	1 ips	1,000 lbs. stall force
Mechanical Arm (Mod.500)				
Shoulder Rotate	About an axis parallel to the longitudinal axis of the boom	360° continuous	3 rpm	200 lb. ft.
Shoulder Swing	About an axis perpendicular to shoulder rotate axis	200°	240° per min.	100 lb. lift at hand, upper arm & forearm horizontal 240 lb. lift at hand, upper arm horizontal & forearm vert. 2,000 lb. lift (using hook), upper arm & forearm vert.

*Vertical motion derived from elevator hoisting is omitted.

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Elbow Swing	About an axis perpendicular to axis of upper arm	180°, $\pm 90^\circ$ from axis of upper arm	480° per min.	160 lb. lift at hand, forearm horizontal & upper arm vert.
Wrist Rotate	About an axis parallel to axis of forearm	360° cont.	8 rpm	60 lb.ft.
Hand or	Mounted on outer end of wrist	7½" max. open	20"/min.	280 lb. closing force
Hook	Interchangeable with hand	3 1/8" max. open	8"/min.	1,000 lb. closing force

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4. CONCLUSION

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The design of a successful Rear-Face Manipulator, as presently conceived, must incorporate the abilities and requirements listed in the foregoing specifications and it must also be remembered that a successful design should anticipate further requirements which may only become apparent in actual operation. For this reason, specifications should be kept as general as practical and additions and refinements should be anticipated.

General Mills, Inc. believes that the foregoing specifications are reasonable and feasible and that a successful rear-face manipulator system can be developed using these specifications as a guide to the general design.

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22 September 1958

PROPOSAL 8-3012
DETAIL DESIGN, FABRICATION, AND TESTING
of a
PROTOTYPE UNDER-ELEVATOR MOUNTED
REAR-FACE MANIPULATOR

Prepared for
GENERAL ELECTRIC COMPANY
Hanford Atomic Products Operation
Richland, Washington

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*For monitoring Rear-Face Manipulator position relative to the elevator. For complete monitoring system - see also Plans 3.1.2 and 3.1.3

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**Items not furnished by General Mills, Inc. as part of this proposal.

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PROPOSAL 8-3012

1. INTRODUCTION

As a requirement of Design, Development, and Research Contract DDR-42, Prime Contract W-31-109-Eng-52, 15 May 1958, General Mills, Inc. has prepared a layout design for the Under-Elevator Mounted Rear-Face Manipulator to be employed in reactor discharge-area maintenance. This device itself will be similar to that shown on Drawing 222944-E (sheet 1 of 2) appended; the overall system will be similar to that shown on Drawing 223860-E, also appended. As a further requirement of Contract DDR-42, General Mills, Inc. is pleased to submit this proposal.

In the Table of Contents, items not included in the cost estimate accompanying this proposal and not furnished by General Mills, Inc., are double-asterisked (**) since these items were not originally considered necessary to the system. Included in the cost estimate, however, is the simple transfer dolly originally intended to aid machine loading from dolly room to elevator.

If the General Electric Company so desires, General Mills, Inc. will be happy to submit a proposal for the extra equipment at a later date.

2. SUMMARY

During the 3-month period from 15 May 1958 to 10 August 1958 designated by Contract DDR-42, later amended to expire 10 September 1958, General Mills has completed a feasible design for an Under-Elevator Mounted Rear-Face Manipulator. Close liaison and frequent conferences with the General Electric Company have enabled considerable refinement and a workable overall system.

As presently envisioned by both General Electric Company and General Mills, Inc., this system requires equipment the need for which was not originally planned, i.e., a "remote-removal tractor" to enable automatic transfer and loading of the RFM from dolly-room to elevator. Since the Remote Removal Tractor has become a fairly complex machine in itself, it was mutually agreed between General Electric Company, and General Mills, Inc. that its design lay beyond the scope of the present contract. Although the Remote Removal Tractor is not included in this proposal, its requirements have been studied and suitable provisions have been made in the proposed electrical and mechanical systems to permit its incorporation at a later date. Instead, General Mills, Inc. will supply a simple transfer dolly to facilitate machine servicing and manual transfer from dolly room to elevator.

Similarly, General Mills, Inc. suggests the desirability for (but does not include in this estimate) a "retractor cable" and its reeling mechanism designed to permit emergency removal of the RFM from elevator to dolly room in case of machine power- or drive- system failure.

It will also be noted that the dolly room Test Station and the Overall Cell Viewing T-V Monitor are not included as items to be furnished by General Mills, Inc., since these, too, are items not originally considered necessary to the system.

It was further agreed that General Electric Company would assume responsibility for the design and installation of the trail-cable system feeding hydraulic, pneumatic, and electric power to the RFM. Because the General Electric Company's Cap-Remover requirements are not yet fully determined and since reactor-building features and other necessary information is not readily available to General Mills, Inc., it was felt that on-site

General Electric Company personnel would be better able to set up the trail-cable system -- perhaps by modifying the system presently installed in 105-K Building.

Consequently, while they are discussed and have been studied, these 5 groups of equipment --

- 1) Remote Removal Tractor,
- 2) Trail-Cable System,
- 3) Test Station,
- 4) Emergency Retractor Cable, and Reeling System,
- and 5) Overall Cell Viewing T-V Monitor ---

are not included in the cost estimate accompanying this proposal. Instead, to facilitate prototype testing, General Mills, Inc. intends to furnish a sufficient amount of 36-conductor cable and $\frac{1}{2}$ -inch air and water lines plus a waterproof junction box and a hydraulic/pneumatic manifold for test purposes. This equipment is included in the cost estimate as itemized.

As stipulated in General Mills, Inc. previous Proposal #86015, a sixth group of equipment not to be furnished by General Mills includes the Elevator End-Play Monitor and the elevator's vertical position monitoring system (Coarse Vertical Position Monitor) and the associated cams. This equipment is, however, discussed here as part of the required system but it will actually be furnished by the General Electric Company.

As an additional aid to the program General Mills, Inc. has prepared and furnished an estimate of rail installation time, cost, most feasible method, and special gauges, fixtures, etc., required to effect rail installation in minimum time. This report is duplicated in the Appendix.

For proposal and estimating purposes, the design as shown on appended drawings 222944-E and 223860-E will be considered fixed. The overall system is comprised of equipment part of which will be furnished by General Mills, Inc. and part by the General Electric Company. As the system is

discussed, each company's responsibility for particular parts will be noted. Alterations in design from that shown may later be requested and it is expected that such changes can easily be negotiated.

Functional specifications developed to guide the general design of a Rear-Face Manipulator will be found in the separate report, "Specifications for a Prototype Under-Elevator Mounted Rear-Face Manipulator".

3. SYSTEM LAYOUT AND COMPONENTS

The Rear-Face Manipulator will be discussed as a complete system involving four major areas: 1) Rear-Face Area, 2) Dolly Room, 3) Control Room, and 4) Electrical Equipment Room. The system consists primarily of the Rear-Face Manipulator itself, its trail-cable system, a master control console, and the intermediate electrical control equipment. Secondary equipment includes a test station having duplicate basic controls, a remote-removal tractor for servicing, loading and unloading the machine from the elevator, and an emergency retractor cable with its reeling system to remove the machine from the elevator in case of power failure. It should be noted here that, due to the limited scope of Contract DDR-42 and by mutual agreement between the General Electric Company and General Mills, Inc. the trail-cable system, the remote-removal tractor, the emergency retractor cable and reeling system, the test station, the over-all cell-viewing television monitor, and the elevator position monitors (coarse vertical and end play) with their associated cams are not considered a part of this proposal. While they are included in the discussion and have been studied, they are not a part of the cost estimate. As previously stipulated, however, General Mills, Inc. will furnish the necessary cabling and accessories required to adequately test the prototype.

3.1 Rear Face Area Equipment

In the Rear Face Area three groups of system components are immediately apparent:

- 1) the Rear Face Manipulator,
- 2) equipment permanently attached to the elevator, and
- 3) wall and floor mounted equipment.

.1.1 Rear-Face Manipulator

The Rear-Face Manipulator consists of 1.) a main carriage riding on rails mounted beneath the elevator and carrying a vertically adjustable boom, 2) a manipulator carriage carrying 2 smaller auxiliary carriages and the Mechanical Arm and providing movement into and away from the reactor face, 3) a dual-camera television monitoring system which provides both work-area monitoring and visual position-sighting, 4) a system of flood lights, and 5) a position-monitoring system capable of accurately determining the location of the machine with respect to any process tube in the rear face lattice.

.1.1.1 Main Carriage

The Main Carriage is a welded aluminum frame providing a means for mounting the 1) drive truck, 2) wheel trucks, 3) boom, 4) boom-raise mechanism, 5) T-V camera mounts, 6) hydraulic/pneumatic system components, 7) electrical system components, and 8) the retractible limit stop.

Drawing 222944-E (2 shts.) illustrates the overall assembly.

.1.1.1.1 Drive Truck

As illustrated by Drawing 223586-E, the Drive Truck is an aluminum weldment carrying a centrally-located, airmotor-driven, worm-type, 15:1 speed reducer whose double-extended out-put shaft drives a pinion at each end of the truck. Each pinion is electric-slip-clutch protected and is automatically disconnected from the drive shaft in emergency. The Drive Truck is capable of exerting sufficient stall torque to develop a rack-force of 1,000 pounds. It will drive the machine at a top speed of 50 fpm and is capable of exerting a 200-pound rack force at this speed. The air motor-worm drive characteristics are such that for each 5 fpm drop in machine speed, available rack force approximately doubles.* The airmotor is clutch-connected to the worm and this clutch, the worm reducer, and the electric clutches (which permit infinitely variable angular adjustment of the pinions relative to each other) are contained in a common sealed housing and all exposed parts are corrosion resistant. It should be noted here that a water-motor drive was not selected because: 1) a suitable motor is not presently available, 2) physical size in general is large, and 3) with working pressures from 60 psi to 100 psi, required fluid flow rates are beyond practical limits dictated by supply line sizes.

* Note Appendix for drive system calculations.

.1.1.1.2 Wheel Trucks

The Wheel Trucks, a section of which is also illustrated in Drawing 223675-E are simple weldments of structural aluminum. A single tubular shaft is clamped in each and carries a vee-grooved, sealed, bronze wheel at either end.

.1.1.1.3 Boom

Drawing 222944-E shows the Boom, pivoted at the rear, hung between cross-members of the main carriage frame. It is fabricated from structural aluminum and carries a stainless steel rail on each side to support the manipulator carriage. The Boom is pivotable through a small angle to provide means for fine vertical adjustment within a 4-inch range at the nozzle tips.

.1.1.1.4 Boom-Raise Mechanism

As illustrated by Drawing 222807-D, the Boom-Raise Mechanism is an airmotor-driven, worm-type, 15:1 speed reducer (drawing 222808-C) whose double-extended output shaft is fitted with a crank at each end and linked to the boom, thus permitting smooth and accurate boom positioning. The mechanism is capable of developing 1000-pound net lifting force at the forward tip of the boom.

.1.1.1.5 T-V Camera Mountings

The T-V Camera Mountings shown on Drawing 222944-E provide a pivotable base to enable a pair of

special cameras to be trained on the work area or aimed straight forward at the process-tube caps for position-locating purposes. A small water-cylinder provides the pivoting actuation.

1.1.1.6 Hydraulic/Pneumatic System Component Mounting

As generally indicated on the overall assembly drawing, a place to mount solenoid valves, hydraulic/pneumatic manifolds, etc., will be provided on one side of the main frame. Valves will be mounted on a common-manifold in so far as possible.

1.1.1.7 Electrical System Component Mounting

On the outside of the main frame, probably opposite the hydraulic components, the electrical junction box receiving machine power and control cables will be mounted. This will be a waterproof box, air-purged, and stainless-conduit-connected to auxiliary boxes elsewhere on the machine. (The entire junction-box-conduit system will be constantly air-purged.)

1.1.1.8 Retractable Stop and End Limit Switches

Although not indicated on drawing 222944-E, a solenoid-actuated mechanical "stop" will be mounted on the main frame to prevent machine over-travel at either end of the elevator in case of electrical limit-switch failure. The

"stop" will be retracted when the machine is removed from the elevator. Similarly, two pairs of limit switches will be carried to indicate travel limits and "squashing" limits in the machine's travel along the elevator. Both mechanical and electrical stops will be positioned to engage cams mounted on the rails.

.1.1.2 Manipulator Carriage

The Manipulator Carriage, illustrated in drawing 222809-D, is a welded framework of structural aluminum. It carries bronze "ways" which slide along the stainless steel rails mounted on the boom. The carriage in turn carries 1) a pair of auxiliary carriages and 2) a General Mills, Inc. Mechanical Arm. Carriage in-out movement is effected by a 6-inch bore water cylinder whose stroke is 18 inches. End limits of the stroke are sensed by appropriately located limit switches and the carriage is spring-returned to its back limit to insure retraction in case of power failure. The carriage is capable of exerting a net force of 1000 pounds in either direction along its axis of movement.

.1.1.2.1 Auxiliary Carriages

Two Auxiliary Carriages are hung between bronze ways beneath the Manipulator Carriage and are located 2 lattice-apace increments either side of center, as indicated on drawing 222809-D. These carriages are fabricated from aluminum and carry

stainless steel vee-rails. They are powered in and out by 6-inch bore water cylinders whose stroke is 26 inches. Each is capable of exerting a net force of 1000 pounds in either direction. To insure emergency retraction, each Auxiliary Carriage is spring-returned to its back limit of travel. End limits are again limit-switch sensed. Thus, two positionable platforms -- remotely controlled -- are provided to carry the Cap-Remover or other special tools,

.1.1.2.2 Mechanical Arm

A General Mills, Inc. Model 500 Mechanical Arm is centered beneath the Manipulator Carriage. The Arm, corrosion-resistant and waterproof, is visually monitored by television and manipulated from the master console in the control room. The Arm will also incorporate a 14-inch upper arm to improve close-range manipulating ability.

.1.1.3 Dual-Camera Television Monitoring System

Two television cameras whose Vidicon tubes incorporate etched cross-hairs are used as combination monitors and secondary machine-locating devices. They are located approximately as shown on drawing 222944-E. In the monitoring position both cameras are tilted downward and inward to focus on a common area. Either or both can be raised to an aiming position perpendicular to the rear face and can be used to align the machine with a particular process tube should the normal

position monitoring system become inoperative. Since the cameras are located a known multiple of lattice-space increments from the machine centerline and thus from the auxiliary carriage centerlines, the Cap-Remover, for instance, can be brought to bear on any selected tube by sighting the camera cross-hair on a second tube whose position relative to the first corresponds to the camera's position relative to the Cap-Remover. The two special cameras are housed in stainless steel, watercooled jackets and include remote focus and iris controls and "windshield" wipers.

.1.1.4 Floodlights

Although not indicated on the overall assembly drawing, a minimum of two floodlights, appropriately housed, will be provided to illuminate the work area. These may be located on the front face of the boom or on the television camera mount.

.1.1.5 Manipulator Position-Monitoring System

A Position-Monitor System as shown in Elementary Electrical Diagram 223664-R will present visual machine-location information at the master console. The system monitors vertical and horizontal position and senses in-out carriage travel limits and "arm-folded" position. That part of the system carried on the Rear-Face Manipulator and furnished by General Mills, Inc., will be discussed in this section. Those components of the system which are carried on the elevator and furnished by the General Electric Company will be discussed in the section headed, "Elevator-Attached Equipment."

Five parts will be considered here; 1) main-carriage travel monitoring, motion "X", effected by the Horizontal Position Monitor, 2) boom position monitoring, motion "Y₁", determined by the Fine Vertical Position Monitor, 3) manipulator-carriage in- out limit sensing, motion "Z", depending on limit-switch actuation, 4) auxiliary carriage in-out limit sensing, motion "Z₁", also depending on limit-switch actuation, and 5) "Arm Stored" sensing, or Mechanical Arm folding. Although the monitoring synchros and their respective gear trains are not shown in mechanical layout form, they are sufficiently clear on the electrical diagram 223664-R.

.1.1.5.1 Horizontal Position Monitor

Rear-Face Manipulator travel along the elevator, Motion "X", is monitored by a synchro system mounted on the Main Carriage frame and engaging the drive rack carried on the rails. This Horizontal Position Monitor, a single synchro generator, feeds continuous position information through the Elevator End-Play Monitor (a synchro differential generator) to the appropriate synchro control transformer in the control console.

.1.1.5.2 Fine Vertical Position Monitor

Boom position, motion "Y₁", which permits accurate vertical positioning, is sensed by the Fine Vertical Position Monitor. This system incorporates a synchro differential generator suitably

coupled to the boom raising mechanism and also fed by the Vertical Position Monitor which is a synchro generator mounted on the elevator. The differential generator sensing boom position is thus able to electrically add or subtract from the elevator's position signal (Y), depending on whether the boom is above or below the mid-position. The combined signal is then transmitted to the control console.

.1.1.5.3 Manipulator Carriage Insert-Retract Limit Sensing

The Manipulator Carriage is capable of a total travel of 18 inches (motion Z) toward the reactor face from its back limit. Since the carriage is normally used either fully "in" or fully "out", its position is sensed only at each end limit by limit switches fixed to the boom frame and controlling indicator lights on the console. Intermediate positions are television monitored.

.1.1.5.4 Auxiliary Carriage Insert-Retract Limit Sensing

The two Auxiliary Carriages have motions (Z_1) similar to the Manipulator Carriage but with travels of 26 inches with respect to that carriage. Their end limits are also limit-switch sensed and so indicated at the control console.

.1.1.5.5 "Arm Stored" Sensing

During cap-removing operations, etc., and normal machine movements along the elevator and particularly

during machine transfer and loading from dolly room to elevator, the Mechanical Arm must be folded into a "stored" position beneath the Manipulator Carriage as shown on drawing 222944-E. Its movements are visually monitored via television but a positive indication of its completely folded state is effected by limit switches located within it.

.1.1.6 Hydraulic/Pneumatic System

All basic Rear-Face Manipulator motions (except in the Mechanical Arm) are effected either hydraulically or pneumatically as shown on drawing 223766-E. Not shown on this drawing are the electrical junction box air-purging system and Cap-Remover control circuitry. The system will be so fabricated that, if prototype testing indicates the need, modifications or additions can be relatively easily made by General Electric Company personnel.

All components of the system are specially fabricated to resist corrosion and heat and are submersible.

.1.1.6.1 Hydraulic System

As illustrated in drawing 223766-E, the Hydraulic System employs plant process-water at 60 psi to 100 psi -- the approximate range of Hanford's reactor-cooling-water pressure. System water will be carried to the machine via two, $\frac{1}{2}$ -inch flexible hoses terminated in corrosion-resistant quick-disconnect fittings at the master manifold mounted on the main frame.

Drive-cylinders are large bore to improve "inching" and "locking-under-load" characteristics and supply and exhaust lines can be individually orificed to control flow rates. Automatic "dumping" and retraction is provided in case electric power fails. Selective "dumping" is possible in the event of hydraulic power failure. The system is protected by appropriately placed relief valves should external forces develop unsafe system pressures.

As drawing 223766-E illustrates, flow direction and volume are controlled by solenoid-operated valves which permit cylinder "inching" and "locking." As previously noted, all parts are corrosion resistant and able to withstand both submersion and 100° C temperatures. Flexible lines will be terminated in "quick-disconnect" type connectors while fixed lines will be made from stainless steel tubing. Wherever possible, components will be grouped in a common area and sub-plate mounted between common supply and exhaust manifolds.

.1.1.6.2 Pneumatic System

Pneumatic System layout and fabrication techniques will be similar to those employed in the Hydraulic System. General Mills, Inc. will furnish a master intake manifold and a master exhaust

manifold mounted on a common base plate which will provide mounting space for the sub-plate-mounted solenoid valves with which the General Electric Company will control its Cap-Remover. Supply air lines will be two, $\frac{1}{2}$ -inch flexible hoses terminated in corrosion-resistant quick-disconnect fittings at the master manifold.

"Corrosion proof," solenoid-operated valves will control flow direction and volume as in the hydraulic system. As illustrated, speed control in the Main Carriage Drive circuit is available in 7 steps by switching the exhaust through various combinations of adjustable preset orifices. The two airmotors will be fixed-displacement types, corrosion-resistant, and easily changeable.

1.1.7 Electrical System

Electric power and control cabling required by the Rear-Face Manipulator will be brought into the machine via three 36-conductor, neoprene jacketed, flexible cables terminated in submersible connectors at a master water proof junction box. Successive waterproof junction boxes on the boom, Manipulator Carriage, and Auxiliary Carriages will distribute the power and control circuits. All connectors will necessarily be waterproof and corrosion resistant, conduit will be stainless steel, and flexible cabling will be neoprene jacketed.

3.1.2 Elevator-Attached Equipment

Equipment permanently attached to the elevator includes, 1) rails, 2) the elevator end-play monitoring system, and 3) a multipurpose cam. These three groups of equipment will remain in the Rear Face Area and will require

special consideration to insure dependability and as good as possible resistance to radiation and corrosion. Further, simplicity of installation is paramount, since installation costs are exceedingly high. (Note the special report "Rail and Manipulator Installation Estimate", included in the Appendix.)

3.1.2.1 Rail Assemblies

As illustrated by drawings 223401-D, 223675-E, and 223860-E, the Rear-Face Manipulator will travel along the elevator on rail assemblies mounted on the lower inside surfaces of the I-beam flanges. These assemblies will be adjustably mounted on pads welded to the beam flanges. Essentially, the rails are fabricated entirely from stainless steel in keyed 10-foot sections by welding an inverted angle to a bed-plate. The bed-plate also serves as a mounting surface for, 1) the drive-rack and 2) the required travel-limit cams.

1.2.1.1 Drive Rack

The Drive Rack will be machined from stainless steel and bolted and doweled to the underside of the bed-plate. Dimensions and specifications are shown on drawing 223675-E.

1.2.1.2 Travel Limit Cams

Six cams, suitably mounted on the rail assemblies, will be required to perform travel-limiting functions. Two of each of the following types will be installed: 1) squashing stops; 2) end-travel limits, electrical and mechanical.

1.2.1.2.1 Horizontal Squashing Stops

When fully bottomed, the elevator is permitted to rest on concrete pads, one under each end. Serious damage could result if the Rear-Face Manipulator were run into a pad while the elevator was lowered beyond its "squashing limit". A cam fixed to the rail near each end will actuate a limit switch to prevent machine entry into the squashing area whenever the elevator is below a safe limit. These switches cannot be overridden unless the elevator is above the squash-point.

1.2.1.2.2 End-Travel Limits

To prevent accidental over-travel, travel-limiting cams located at each end of the rails provide means for both mechanically and electrically limiting machine travel.

1.2.1.2.2.1 Electrical Limits

A cam at each end of the elevator-mounted rails will actuate the appropriate limit switch carried on the Rear-Face Manipulator and thus interrupt its drive.

1.2.1.2.2.2 Mechanical Limits

To positively prevent the machine from accidentally running off its tracks should electrical limit switches fail, a cam at each rail-end, located just outboard of the electrical limits, will engage a solenoid-controlled stop fixed to the machine frame.

1.2.1.3 Elevator-Remote-Removal Tractor Alignment Stops

Although not furnished by General Mills, Inc. nor illustrated on General Mills' drawings, means must be provided to permit remotely controllable alignment between elevator rails and the rail-sections carried by the Remote Removal Tractor. This will probably be a single mechanical stop fastened to the dolly room rail-ends. It will provide a reference for horizontal and vertical alignment and for end-engagement.

.1.2.2 End-Play Monitor (Motion " X_1 ")

Since its vertical ways permit the elevator a certain amount of unavoidable end play, a synchro differential generator is arranged to sense this motion, X_1 , add it to the horizontal position signal, X , received from the machine, and transmit the combined signal to the control console to show horizontal machine location in the X-coordinate. The End-Play Monitor, not furnished by General Mills, Inc., is shown on electrical diagram 223664-R.

.1.2.3 Multipurpose Cam

A single cam, not shown on General Mills, Inc. drawings nor furnished by General Mills, Inc., will be mounted on the dolly-room end of the elevator to serve as a reference for dunking stop, vertical squashing stop, and to indicate when the elevator is in position to permit machine-transfer to or from the proposed Remote Removal Tractor. The cam will actuate appropriate limit switches, not furnished by General Mills, Inc., mounted on the elevator ways.

3.1.3 Wall and Floor Mounted Equipment

The third group of Rear-Face Area equipment includes all items not mounted on either the Rear-Face Manipulator or the elevator. This group includes 1) limit switches, 2) an over-all cell-viewing television monitor, and 3) the coarse Vertical Position Monitor. This equipment will not be furnished by General Mills, Inc.

1.3.1 Limit Switches

Limit switches, to be provided by the General Electric Company and probably mounted on the elevator's ways, will sense its

1) dunking limit, 2) squash limit, and 3) loading position. The switches will be actuated by the previously mentioned multipurpose cam.

.1.3.1.1 Dunking Limit Switch

This switch will stop elevator down-travel beyond the point where the Rear-Face Manipulator begins to submerge in the basin. Over-ride will be provided for deliberate dunking.

.1.3.1.2 Vertical Squashing Limit Switch

In conjunction with the squashing stop which limits machine travel over the elevator pad area, the Vertical Squashing Limit Switch will prevent elevator down-travel which might damage the machine if the elevator were lowered too far while the machine is positioned over either pad. This switch cannot be over-ridden unless the machine is clear of both pad areas.

.1.3.1.3 Machine-Loading Range Limit Switches

A limit switch, evident in electrical diagram 223664-R, will determine the range within which the elevator must be located in order to effect a machine loading cycle in conjunction with the Remote Removal Tractor.

.1.3.2 Overall-Cell-Viewing Television Monitor

A third specially-adapted television camera, not included in system components nor furnished by General Mills, Inc., will be similar to the two cameras carried on the machine but will probably employ a "2-inch" telephoto lens and will incorporate remote focus, iris, and tilting. It should not require panning ability

since it will be mounted on the cell floor at the end of the elevator opposite the dolly room and can thus cover all machine movements plus observing the dolly room doorway.

.1.3.3 Coarse Vertical Position Monitor

Since the elevator provides coarse vertical travel for the Rear-Face Manipulator, it requires its own position-monitoring system. As shown in electrical schematic 223664 R, a synchro generator, suitably linked to the elevator hoisting mechanism, feeds through the boom-position-sensing synchro differential generator to the control console. Coarse vertical motion, "Y", is thus continuously monitored and compared with boom position, "Y₁" to determine vertical machine location in the Y-coordinate.

.1.3.4 Monitoring System Calibration Stop ("X" Zeroing)

Each time the Rear - Face Manipulator is removed from the elevator, the X-coordinate monitoring system must be recalibrated. Since the existing elevator ways permit some end-play, the machine must be "zeroed" from a reference whose physical location relative to the reactor face does not change -- hence the need for a mechanical stop fixed to the "near side" elevator ways against which the machine can be run to reference itself. This stop, furnished by the General Electric Company, will then permit the monitoring system to be calibrated with assurance that the reference position remains constant.

3.2 Dolly Room Equipment

As presently visualized, four groups of equipment will be required in the dolly room. These groups will include 1) a test station, not furnished by

General Mills, Inc., to provide manual control of machine functions for test purposes, 2) a tractor or dolly, not part of this proposal, remotely controllable, to permit the Rear-Face Manipulator to be loaded on or off the elevator, 3) the trail-cable assembly furnished by the General Electric Company, to supply machine power, and 4) an emergency machine-retracting cable, not part of this proposal, which can pull the machine off the elevator and onto the Remote Removal Tractor in case of machine power failure.

.2.1 Test Station

Also located in the dolly-room to permit direct visual observation of all machine movements for test purposes is the Test Station, not furnished as part of this proposal. This station includes a pair of GMI hand grips, appropriate indicator lights, and the necessary manually controlled switches to effect any desired motion. Elementary Electrical Diagram 223664-R shows how the Test Station ties into the normal control circuitry. Thus, the Cap-Remover or the Mechanical Arm as well as boom and Manipulator Carriage or Auxilliary Carriage movements can be easily checked. Sufficient space will be included to later install manual controls and indication for Remote Removal Tractor motion checking.

.2.2 Remote Removal Tractor

Preventive maintenance as well as regular operational checking must be easily effected to insure the successful performance of any machine intended for 24-hour standby as an emergency maintenance tool. To permit service of this sort, the machine must be quickly removable from the reactor rear-face area, hence the necessity for the proposed

Remote Removal Tractor. This tractor, normally stored in the dolly room, could be sent into the highly radioactive rear face to automatically unload the Rear-Face Manipulator from the elevator without requiring reactor shut-down and then to carry the machine back to the shielded confines of the dolly room, all without human exposure to high-level radioactivity. The tractor would incorporate the ability to 1) travel from the dollyroom to the elevator end, 2) align itself with the machine rails mounted on the elevator, 3) sense the aligned condition, 4) receive the machine on its mating rails, and 5) retract to the dolly room. The removal cycle and its reverse, the loading cycle, would be automatically sequenced and controlled from the master console. Electrical diagram 223664-R presently provides for this sequence although neither design nor fabrication of the Remote Removal Tractor is considered a part of this proposal.

As originally proposed, General Mills, Inc. will supply a simple transfer dolly, hand-crank driven, to facilitate maintenance and to aid in loading the machine on the rear-face elevator. The transfer dolly will carry the machine on cantilevered rails similar to the rails to be installed on the elevator I-beam flanges and, when the elevator is properly positioned, will enable the machine to be rolled out from inside the dolly room and driven onto the elevator.

2.3 Trail-Cable Assembly

The Trail Cable Assembly, furnished by the General Electric Company is expected to consist of 1) two trail-cables and hoses, 2) an electrical junction box, 3) a hydraulic/pneumatic manifold, and 4) the cable take-up mechanism. The assembly will feed power and

control signals through a series of trailing cables to the machine as it moves vertically and horizontally across the reactor rear face. Items 1, 2, and 3, sufficient for prototype testing, (cable and hose, 50 feet each), will be supplied by General Mills, Inc. Item 4, the Cable Take-Up Mechanism, will be furnished by the General Electric Company as mutually agreed.

.2.3.1 Trail-Cables and Hoses

At this time it is anticipated that three 36-conductor electrical cables, two $\frac{1}{2}$ -inch water lines, and two $\frac{1}{2}$ -inch air lines will be sufficient to supply machine power and control requirements. These cables and hoses will be flexible, suited to reeling, waterproof, and heat-resistant. They will be terminated in corrosion-resistant quick-disconnect plugs or waterproof screw-type electrical connectors. Since damaging radiation effects are expected to occur in time, the cables and hoses must be easily replaceable

.2.3.2 Junction Box

A waterproof stainless steel junction box is provided by General Mills, Inc., at which to terminate the trail cables. From the electrical equipment room, cable entry to the box will be via conduit; from the machine, via submersible connector.

2.3.3 Hydraulic/Pneumatic Manifold

In a fashion similar to that employed in the electrical system, a hydraulic/pneumatic manifold is provided at which to terminate water and air lines.

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.2.3.4 Cable Take Up Mechanism

Trall cables and hoses feeding power to the Rear-Face Manipulator will be pulled out from and reeled back to the Cable Take-Up Mechanism as required by the combined elevator-and-machine movements. The mechanism will also permit the machine to be remotely transferred to and from the Remote Removal Tractor and thence to the lollyroom.

.2.4 Emergency Retractor Cable Assembly

Means should be provided to remove the Rear-Face Manipulator from any position on the elevator if the machine drive is disabled. To effect this emergency removal, a retractor cable assembly is suggested (but not included in the proposal) which could mechanically pull the machine along the elevator onto the removal tractor when desired but which would not otherwise interfere with machine movements. The cable reeling system would necessarily be designed to permit the retractor cable to follow machine movements about the rear face, maintaining a constant light cable tension when either reeling up or paying out, and at the same time having the ability to forcefully wind in, pulling the machine off the elevator. As previously noted, the Emergency Retractor Cable Assembly is not a part of this proposal or cost estimate.

3.3 Control Room Equipment

Rear Face Manipulator operation and monitoring will be effected from the Control Room. All manual controls and indication evident in electrical

schematic 223664 R will be located in a special control console furnished by General Mills, Inc. together with the two television receivers.

Drawing 223678-E (2 sheets) illustrates the general arrangement of manual controls, control hand-grip, and visual indication presented at the console. The right hand-grip will be used exclusively for Mechanical Arm Control. The left hand-grip can be selectively made to control 1) the elevator (Y), the higher speeds of the main carriage (X), and the Manipulator Carriage In-Out movement (Z), 2) the boom position (Y₁), the low speed of the main carriage (X), and the Manipulator Carriage In-Out movement (Z), or 3) Cap Remover functions. The necessary manually-operated switches and keys or push-buttons are grouped to permit natural and logical hand-movements.

3.4 Electrical Equipment Room

General electrical control equipment furnished by General Mills, Inc. will be housed in the Electrical Equipment Room. This equipment will include all intermediate circuitry, relays, etc., required between the console and the machine and all circuitry common to console and Test Station. It will be suitably housed and will provide test jacks, conveniently grouped, to permit fast circuit checking.

4. Table of Machine Motions, Locations, and Capacities

The following table summarizes the motions (and their locations and capacities) effected by the Rear-Face Manipulator as proposed by General Mills, Inc. These motions are exclusive of vertical travel provided by the rear-face elevator and do not include motions generated in the Cap Remover or other special tools.

TABLE OF MACHINE MOTIONS, LOCATIONS, AND CAPACITIES*

Motion	Location	Travel	Max. Rate	Capacity
1. Main Carriage Travel	On rails along the longitudinal axes of the elevator I-beams	50 ft.	50 fpm	1,000 lbs. stall force
2. Boom Raise	Pivot about a horizontal axis parallel to rails and located at rear of machine	2°, 20' to produce 4" adjustment at reactor face	360°/min.	1,000 lbs. net lifting force at tip
3. Manipulator Carriage Insert/Retract	On rails along the longitudinal axis of the boom	18 in. relative to boom	1 ips	1,000 lbs. stall force
4. Auxilliary Carriages (2) Insert/Retract	On rails along the longitudinal axis of the manipulator carriage	26" relative to manip.car.	1 ips	1,000 lbs. stall force
5. Mechanical Arm (Mod.500)				
.1 Shoulder Rotate	About an axis parallel to the longitudinal axis of the boom	360° continuous	3 rpm	200 lb.ft.
.2 Shoulder Swing	About an axis perpendicular to shoulder rotate axis	approx. 200°	240° per min.	100 lb. lift at hand, upper arm & forearm horizontal 240 lb. lift at hand, upper arm horizontal & forearm vert. 2,000 lb. lift (using hook), upper arm & forearm vert.

*Vertical motion derived from elevator hoisting is omitted.

.3 Elbow Swing	About an axis perpendicular to axis of upper arm	180°, = 90° from axis of upper arm	480° per min.	160 lb. lift at hand, forearm horizontal & upper arm vert.
.4 Wrist Rotate	About an axis parallel to axis of forearm	360° cont.	8 rpm	60 lb. ft.
.5 Palm	Mounted on outer end of wrist	7½" max. open	20"/min.	250 lb. closing force
=				
Hook	Interchangeable with hand	3 1/8" max.	8"/min.	1000 lb. closing force

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5. OPERATION AND ELECTRICAL CONTROL

Remote maintenance on a Hanford reactor rear-face requires a machine whose primary functions are 1) location, 2) insertion, and 3) manipulation. Since maintenance operations are performed in a complex lattice-work of process-tube nozzles and valves located in a space approximately 48 feet long, 34 feet high, and 3 feet deep, the machine must first have the ability to be accurately positioned on the proper horizontal and vertical coordinates in front of the work area. Second, having been located, the machine must insert into the work area certain special maintenance equipment which it carries. Third, the machine must approximate the manipulative ability of the human hand in effecting assembly or disassembly of small parts as well as being able to operate manually controlled 4-inch valves. In addition, the machine must be simple to operate, easy to maintain, dependable, and "fail-safe." With the foregoing requirements as guides, General Mills, Inc. has designed the Rear-Face Manipulator proposed here. General mechanical operation of the system will be summarized first, and electrical operation will then be discussed.

5.1 Operation

To illustrate typical Rear-Face Manipulator operation, a cap-removing sequence will be outlined.

Normally stored in the dolly-room with both dolly room doors closed, the machine rests on rail sections carried by the Remote-Removal Tractor. In the following steps, the Rear-Face Manipulator is transferred to the elevator, positioned, effects its work, and is returned to storage:

- 1) Rear-Face Manipulator is energized, engaging its drive clutches.
- 2) Remote-Removal Tractor is energized, engaging its drive clutches.
- 3) Elevator is positioned in its "machine-loading" range.

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- 4) Inner dolly-room door opens.
- 5) Remote Removal Tractor runs out to elevator and aligns itself with the machine rails.
- 6) Rear-Face Manipulator runs onto elevator under its own power to the "near" limit.
- 7) Remote-Removal Tractor disengages and returns to its dolly room "home" position.
- 8) Dolly-room door closes.
- 9) Calibration is checked and correction is effected by manually "zeroing" position -- indicating system, if required.
- 10) Elevator is driven to desired vertical location.
- 11) Rear-Face Manipulator is driven horizontally to proper location.
- 12) Manipulator carriage is inserted.
- 13) Cap-Remover carriage is inserted.
- 14) Cap-Remover is operated, T-V monitored.
- 15) Cap-Remover is retracted.
- 16) Elevator is lowered to "machine-loading"
- 17) Dolly-room door opens.
- 18) Remote-Removal Tractor runs out and aligns itself.
- 19) Rear Face Manipulator runs off elevator onto tractor.
- 20) Remote-Removal Tractor returns to dolly room.
- 21) Dolly room door closed.
- 22) Remote-Removal Tractor is de-energized.
- 23) Rear-Face Manipulator is de-energized.

Since a cap-removing operation has been summarized as typical procedure, operations employing auxilliary tools or Mechanical Arm manipulation will not be discussed in detail and it may be merely noted that these would occur as in steps 12 through 15.

5.2 Electrical Control

Primary control of the Rear Face Manipulator will originate at the Control Console, illustrated by drawings 223678-E (2 sheets) and 223664-R. A general description of console functions and electrical system follows: While detailed circuit operation is not described, drawing 223664-R shows in detail the electrical circuitry necessary to accomplish the described functions.

.2.1 Operation Selection

Before initiating RFM operation, the operator selects the desired mode of operation with the "Operation Selection" switch on the panel front. He energizes the system by activating the "Power On" pushbutton and the following operations are then selectable through the "Operation Selection" switch:

.1.1 Elevator and Main Carriage Run Position

This position allows movement of the elevator, main carriage and boom at all controlled speeds. However, before any motion can be initiated, the Mechanical Arm must be "homed", as indicated by arm-motion "Home" lights. Arm folding is necessary to insure that no interference exists between Arm and discharge piping before machine motion is permitted. As noted earlier, the left hand-grip is used for Mechanical Arm control. The up down movement of this control handle serves for both elevator control (coarse vertical) and boom control (fine vertical) as selected by the fine-coarse switch located near the control handle. Referring to drawing 223664-R it may be seen that movement of the control handle

causes relay operation through switches actuated by the control handles. These relays in turn control the solenoids necessary to select the desired drive-motor speed and direction. In addition to the arm "Home" lights previously mentioned, other pilot lights of interest are presented to the operator and since these are clearly shown on drawing 223678-E, they will not be repeated here. These pilot lights, as well as others not presented to the operator but provided within the console as maintenance aids, are all controlled by relays which in turn are operated by limit switches located on the various parts of the RFM. These limit switches will be enumerated later.

.1.2 Arm Control Position

Prior to moving the elevator and main carriage, it may have been necessary for the operator to have homed the mechanical arm carried on the RFM, or the operator may be in a working position where he desires to accomplish remote manipulation with the arm. In either case, the Arm Control position will be selected. The right-hand control handle will then provide natural motion control for driving the five motions of the Mechanical Arm. These are the 1) shoulder swing, 2) shoulder rotate, 3) elbow swing, 4) wrist rotate, and 5) grip. A grip-force indicator is provided on the control console to enable the operator to monitor applied grip force. This circuit, as well as the motor-drives for above motions, is that of the standard GMI Mechanical Arm. All

arm motors will be enclosed within the various arm castings and will have high-temperature windings to allow operation in the severe environment of the rear-face area.

While in the Arm Control mode of operation, only low-speed actuation of the main carriage is allowed. This minimizes the possibility of arm damage when the arm is extended in the rear-face area. Operation of the Mechanical Arm will obviously require television monitoring. This monitoring system is described later.

.1.3 Cap Remover Position

Selecting the Cap Remover position switches the right-hand control handle to relays also used for manually controlling the cap remover. At present, only the cap remover carriage is assigned to this control handle, i.e., the in-out motion of the carriage is controlled by the in-out motion of the right hand. Additional controlled motions will depend on eventual cap-remover design. Space on the left-hand control panel is reserved for additional operator-controls necessary to accomplish cap removing.

An interlock is effected when the cap-remover carriage is moved forward from its retracted position to make the main carriage drive and all vertical motions inoperative. This eliminates any possible accidental misalignment of the cap remover carriage after initiating a cap removal operation.

.1.4 Auxilliary Function Position

This position is reserved for control of apparatus that may be later installed on the auxilliary carriage. This could

include such devices as burst-slug detectors or pig-tail cutters. After selecting this position, the auxiliary carriage may be driven by the lever switch located on the right-hand panel (reserved for future auxiliary control) of the control console. As in the case of the Cap Remover position, selection of the Auxiliary Function position will lock out the vertical and horizontal drives of the RFM.

.1.5 Transfer Position

When it is desired to load or unload the RFM from the elevator, the Transfer position is selected. The elevator is then positioned at the loading location as indicated by the Auto Loading Sequence Preparation light. Further, the RFM carriages must be retracted, the dolly-room equipment homed, and the arm homed. With the above conditions satisfied, the Auto-Ready lights will indicate this condition. Operation of the proper Auto-Start pushbutton will then initiate the desired sequence (either load or unload) indicated by the appropriate Auto-Cycle light. Successful completion of the transfer cycle will be marked by the extinguishing of the Auto-Cycle light.

.1.6 Dolly Room Control Position

When the RFM has been transferred to the dolly room, this condition is indicated by the Manipulator-In-Dolly-Room light. This in turn prohibits assumption of control at the console of any function other than elevator coarse-speed control. A great number of interlocks and automatic sequences are involved in accomplishing the transfer. A more detailed account of this operation will follow in the description of a typical load-unload sequence.

After the RFM is placed in the dolly room, the operator may place the Operation Selector in the Dolly Room Control position. This will allow the dolly room to take over control. This condition will be indicated at the control console. Until released at the dolly room, the control console no longer has any RFM control.

With the RFM in the dolly room and with control switched to this area, parallel controls are provided in the dolly room to operate the carriages, arm, etc., within the limits allowed by the removal tractor. This, of course, will greatly facilitate maintenance and tool-changing. Before returning control of the RFM to the control console, the operator must re-home the RFM to allow automatic reloading of the RFM on the elevator.

.2.2. Position Indication and Calibration

All-important in the operation of the RFM is an exact indication of the position of the working members of the machine with respect to the rear-face lattice. As previously discussed, this position-information is derived from rack-driven synchros appropriately placed. At the control console two methods of "read-out" are provided. The primary system consists of a digital display of the row and column code numbers. Three vernier lights indicate when the displayed numbers are actually on center, off center left, or off center right. A visual display of the numbers is proposed using Nixie number tubes as shown on drawing 223678-E. The secondary position-indication is presented via a five digit mechanical counter enclosed in the control cabinet. This counter provides more accurate position-information for maintenance purposes.

Both indication systems derive their input from the shaft of

the receiving synchro which is caused to accurately follow the transmitting synchros by a servo-motor drive. In the case of the mechanical counter, this consists of simple gearing. For the visual readout of row and column numbers, the shaft system drives a cam shaft carrying three cams which rotates one revolution for each lattice space. At the "on" point of the first cam, the indicated lattice is centered. The next two cams indicate "off center" left and right, respectively. Assuming the "on" cam to be accurate and reproducible to plus-minus 5 degrees in operating the "on" switch, a dimensional accuracy of plus-minus 0.1 inch is indicated, assuming negligible error in the synchro system. Actually, this value is conservative. Following the vernier cams is an analog-to-digital rotary switch with two decades (such as a Digitron). The output of this switch is wired to the appropriate Nixie-tube contacts for the digital display.

In the case of column indication, three separate analog-to-digital switches are used, (one for each auxiliary carriage and the third for machine-center) since the auxiliary carriages are offset. Thus, three separate sets of column numbers are available for a single main-carriage location. While each switch has its contacts appropriately wired to the Nixie tubes, only one switch at a time has its wiper contact energized as determined by the Operation Selector position so the proper column number is always displayed. Row indication is similarly achieved.

Whenever the RFM is removed to the dolly room there is a chance that calibration may be lost. Thus, after reloading the RFM, the main carriage is made to run to a mechanical stop fastened to the elevator ways which are fixed with respect to the rear face.

At this particular point a calibrated column number should appear on center. If calibration has been lost, the operator will operate the recalibrate switch on the control console to restore the proper position indication. This is simply accomplished by declutching the servo-drive and driving the position indicating shaft to the proper position by use of the reset motor.

A similar procedure is followed in checking the row calibration by first centering the carriage boom and then running the elevator to its bottom limit. However, the elevation calibration should not require more than occasional resetting. Additional positional accuracy determination can be made by use of the T.V. monitor cameras which will be equipped with cross-hair reference lines for sighting on rear face reference points.

.2.3 T.V. Monitor

At the control console, two T.V. monitors are provided for viewing RFM operation. The video controls for each of the monitors are located on that monitor, are independent of the rest of the RFM controls, and may be adjusted at any time. Aiming the two machine-mounted cameras is effected by toggle switches located on the control console front panel. The up-limit position for the camera is marked by a limit switch to indicate an "aimed" condition. This "aimed" position will serve as a reference position for the T.V. cameras when using the cameras to sight on specific rear-face points.

.2.4 Limit Switches

Inasmuch as the automatic sequences of loading and unloading the RFM as well as normal operating procedures depend largely on

limit-switch operation, a summary of the various limit switches required, and their locations, is presented below:

.4.1 Elevator-Way-Mounted Switches

1. Elevator Up - SL1
2. Elevator Down - SL2
3. Above Elevator Squash - SL3
4. Above Elevator Dunk - SL4
5. RFM Loading Range - SL5

.4.2 Machine-Mounted Switches

1. Carriage Squash Far - SL32
2. Carriage Squash Near - SL33
3. Manipulator Carriage Retract - SL49
4. Manipulator Carriage Insert - SL20
5. Cap-Remover Carriage Retract - SL24
6. Cap-Remover Carriage Insert - SL25
7. Auxiliary Carriage Retract - SL17
8. Auxiliary Carriage Insert - SL18
9. Arm Shoulder Swing Home - SL23
10. Arm Shoulder Rotate Home - SL22
11. Arm Elbow Swing Home - SL21
12. Boom Up - SL37
13. Boom Down - SL38
14. Boom Center - SL36
15. TV #1 Aimed - SL11
16. TV #2 Aimed - SL14
17. TV #1 Down - SL13
18. TV #2 Down - SL16

19. Carriage Far Limit - SL30
20. Carriage Near Limit - SL31
21. Carriage Mechanical Stop Retract Limit SL34
22. Carriage Mechanical Stop Insert - SL35

.4.3 Dolly Room Mounted Switches

1. RFM on Removal Tractor - SL50
2. Removal Tractor Forward Dolly-Room Limit
(towards elevator but within dolly room) (Home) - SL
3. Removal Tractor Elevator Engage - SL41
4. Removal Tractor Back Dolly-Room Limit (Away from
elevator) - SL43
5. Tractor Vertical-Adjust Up Limit - SL45
6. Tractor Vertical-Adjust Down Limit - SL46 (Home)
7. Tractor Vertical-Align - SL44
8. Tractor Left-Adjust Limit - SL48
9. Tractor Right-Adjust Limit (Home) - SL49
10. Tractor Horizontal-Align - SL47
11. Main Carriage Back-Limit On Tractor - SL52 (Home)
12. Main Carriage Forward-Limit On Tractor - SL51
13. Inner Door Closed - SL6
14. Inner Door Open - SL7
15. Outer Door Closed - SL53
16. Outer Door Locked - SL54

.2.5 Typical Operating Sequence

With reference to the mechanical operating sequence described earlier and consisting of a cap-removing operation, the following electrical functioning is described:

The operator at the control console will select the Transfer

operation and operate the Power-On push button. The Manipulator-In-Dolly Room indicator will light. The operator will then observe the Auto Loading Sequence Preparation lights. Should any of the top row of lights need be lit, with the exception of the elevator's Manipulator-Loading Range light, it will be necessary to put the Operation Selector Switch on the Dolly Room position and send a man into the dolly room to manually "home" the apparatus from that location. However, if the RFM is in the position obtained from a previous unload sequence, all necessary conditions will be met.

The necessary conditions are:

1. Manipulator Carriage Retract Limit
2. Cap-Remover Carriage Retract Limit
3. Auxiliary Carriage Retract Limit
4. Arm Shoulder Swing Homed
5. Arm Shoulder Rotate Homed
6. Arm Elbow Swing Homed
7. Inner Door Closed
8. Outer Door Closed
9. Outer Door Locked
10. Removal Tractor Forward Limit
11. Tractor Vertical-Adjust Down Limit
12. Tractor Horizontal-Adjust Right Limit
13. Main Carriage On Tractor Back Limit

To complete preparations for loading, the operator will then run the elevator to the Manipulator Loading Range. This will light the Auto-Ready light. The operator will then push the Auto-Start button. This

initiates the following sequence (steps 1-10):

1. Inner door opens
2. Removal Tractor engages elevator
3. Removal Tractor vertically aligns
4. Removal Tractor horizontally aligns
5. Main Carriage Mechanical Stop retracts
6. Main Carriage runs onto elevator, Mechanical Stop inserts and carriage drives across to Mechanical Stop
7. Removal Tractor moves to Home in dolly room
8. Tractor adjusts to Down Limit (Home)
9. Tractor adjusts to Right Limit (Home)
10. Inner Door Closes

This interrupts the auto cycle. The operator now switches the Operation Selector to Elevator and Main Carriage position to check column calibration. This is done by operating the Mechanical Stop Override and Electrical Stop Override push buttons simultaneously and running the main carriage against the mechanical stop on the elevator ways. At this point a reference column number should be centered. If it is not, the Calibrate Toggle Switch is operated to bring the indicator into alignment. Having accomplished calibration, the main carriage is returned to within the carriage limit stops by again operating the override buttons and the left control handle. If it is desired to check vertical (row) calibration, a similar procedure is used by overriding the elevator lower limits and resting the elevator against mechanical stops on the concrete pads. Note that this requires the main carriage to be between the squash limits.

After checking calibration, the operator selects the Cap Remover function and with his left hand runs the elevator and main carriage to

the desired cap location. He then actuates the cap removing equipment as required.

To return the RFM to the dolly room, the operator again observes the Auto Loading Sequence lights for required conditions. After locating the elevator at the Machine-Loading Range, the Auto Ready light will light. The operator then actuates the Auto Start button for loading from elevator to dolly room. The sequence of operation is similar to that previously indicated and is as follows:

Steps 1 - 5 Same as previous sequence

Step 6. Main Carriage runs from elevator onto removal tractor to Main Carriage Back Limit On Tracter

Steps 7-10 Same as previous sequence

6. Drawings and Manuals

General Mills, Inc. will furnish one complete reproducible set of the detail design drawings, excepting Mechanical Arm detail-part drawings. Only those detail drawings of the Mechanical Arm required for proper maintenance, mounting, etc. will be included.

General Mills, Inc. will prepare and furnish 20 copies of the necessary instruction and maintenance manuals for the prototype.

7. Method of Attack

Manufacture of the prototype will be carried out in steps, 1) detail design, 2) submission of certified installation drawings, 3) fabrication, 4) testing and inspection. These steps will be programmed approximately as indicated in Item 6.5, Schedule. Close liaison will be maintained between General Mills, Inc. and the Hanford Atomic Products Operation, of the General Electric Company, as the program progresses. Liaison will

begin with a proposal review at Richland, Washington, following receipt of this proposal.

It should be noted that the period required for prototype manufacture is contingent upon receipt by General Mills, Inc. of the rail installation information necessary to permit rail detailing. This information will include a graph of the contour of the lower inside flanges of the elevator I-beams in the area in which the RFM is to be installed. The contour will be determined by measurements taken at 30-inch intervals located per drawing 223401-D, and will include 1) the flange taper and thickness at each of those locations, and 2) the distance between flange lips at each location. In addition, the required information must include elevator pad location and elevator I-beam length. However, if the General Electric Company prefers not to immediately provide for reactor-building installation, the above information is not necessary and rails will be supplied with lugs suitable for "test-area" mounting.

7.1 Detail Design

Detail design will include preparation of assembly and detail drawings required for fabrication of the prototype. These details will follow the general scheme proposed earlier.

7.2 Submission of Certified Installation Drawings

After detailing has become sufficiently complete, certified installation drawings will be prepared and submitted to the General Electric Company's cognizant engineer for his inspection and "approval for content".

7.3 Fabrication

After receipt by General Mills, Inc. of approved installation

drawings, fabrication will be commenced and will occupy a period as indicated in the schedule.

Hanford personnel will be welcomed to General Mills, Inc. shops and laboratories at any time to inspect both design and fabrication as they progress.

7.4 Testing and Inspection

After fabrication is complete, including assembly, the machine will be set upon a short section of track and all motions tested. HAPO will be notified two weeks in advance of this period so that their representatives may be present if desired.

7.5 Schedule

The following chart illustrates General Mills, Inc. phasing schedule proposed for the prototype.

PHASE	PROTOTYPE FABRICATION SCHEDULE													
	Time (in months) elapsed from receipt of purchase order													
	0	1	2	3	4	5	6	7	8	9	10	11	12	13
DETAIL DESIGN	XXXXXX	XXXXXX	XXXXXX	XXXXXX	XXXXXX	XXXXXX	XXXXXX	XXXXXX	XXXXXX	XXXXXX	XXXXXX	XXXXXX	XXXXXX	XXXXXX
SUBMISSION OF CERTIFIED INSTALLATION DRAWINGS						XXXXX								
FABRICATION							XXXXXXXXXXXXXXXXXXXXXXXXXXXX							
TESTING AND INSPECTION												XXXXXXX		
CRATING AND SHIPMENT														XXXX

8. Conclusion

The design of the Elevator-Mounted Rear-Face Manipulator, as presently conceived, incorporates the abilities and requirements listed in "Performance and Operating Specifications for a Prototype Under-Elevator Mounted Rear-Face Manipulator", prepared by General Mills, Inc. for the General Electric Company. Items such as the Remote Removal Tractor, Emergency Retractor Cable Assembly, Coarse Vertical Position Monitor, Elevator End-Play Monitor, Test Station, and other details not originally considered part of the project have been studied, discussed, and in some cases have been designed and appear in General Mills, Inc. drawings. Further additions and refinements probably will result from prototype operation at Hanford.

The design proposed herein, in General Mills' opinion, is sound and very adequately meets the requirements for a reactor discharge-area manipulator.

General Mills, Inc. is pleased to submit this proposal.

APPENDIX

1. "Rail and Manipulator Installation Estimate"
2. Drawing 223860-E, System Layout *
3. Drawing 222944-E, (Sheet 1 & 2) Rear-Face Manipulator Layout *
4. Drawing 223644-R, Elementary Electrical Diagram, Rear-Face Manipulator*
5. Drawing 223678-E (Sheet 1 & 2) Control Console, Rear-Face Manipulator*
6. Drawing 223975-R, Elementary Electrical Diagram, Rear-Face Manipulator;
Manual Loading*
7. Drawing 224001-E (Sheet 1 & 2) Control Console, Rear-Face Manipulator;
Manual Loading*

*Items 2-7 are separately bound and entitled, "Drawing Appendix to Proposal 8-3012, Prototype Under-Elevator Mounted Rear-Face Manipulator."

Rail and Manipulator Installation Estimate

Based on the use of a specially designed installation, maintenance, and storage dolly as illustrated on General Mills, Inc. drawing 222685-E.

1. Establish contours at future pad locations for both front and rear inside bottom I-beam flanges. Accuracy should be at least plus-minus 1/16 to minimize time - consuming final shimming operations. This may be accomplished by:
 - a) Installation of a reference wire along and above the side bottom flanges of both beams and measurements at future pad locations.
 - b) Sighting and measuring rail mounting flanges contours with a wye level or transit of at least 20X. It may be possible, if beam is uniform, to find point of maximum deviation and by calculation arrive at pad heights that are of sufficient accuracy.

It should be noted that this work is of a preliminary nature and must be accomplished, possibly during a scheduled outage, prior to actual start of the installation. If wire is used and its placement does not interfere with operations, the same wire may be used for the final installation of the RFM.

2. Machine pads to desired height and identify each for its pre-selected pad location.
3. Fabricate pad locating fixtures. A complete set of six (6) front rail fixtures and six (6) rear rail fixtures should be fabricated. This will allow pads and fixtures to be assembled by GMI prior to shipment and will eliminate the need to work with potentially contaminated fixtures. A suitable fixture is illustrated on GMI drawing 223676-D.
4. Mount installation dolly on the elevator and equip it with hand tools, welding equipment, paint, etc.
5. Place reactor "near-side" rail end-sections and corresponding pad fixture assemblies on dolly.
6. Move dolly with crew and tools to reactor "near-side" end of elevator (far end of elevator from tool dolly room.)
7. Install reference wires or optical level aligned so that crest of front vee-rail can later be sighted and aligned.
8. Lay first pad fixture assembly in place as marked and in approximate alignment. If necessary to facilitate welding, remove protective paint from I-beam flange at each pad location.
9. Make final pad alignment and clamp fixture in position.
10. Using sequential welding procedure, weld pads into final position, Remove fixture and weld-scale and paint where necessary.

11. Using gauge block measure and place the required shims over the studs on each pad. A suitable gauge block is illustrated on GMI drawing 223676-D.
12. Lay front rail section in position on top of pads and install flat washers and Flex-lock nuts.
13. Accurately align front vee-rail to reference wire or optical level. Tighten all nuts, clamping front vee-rail in final position.
14. Repeat step 11 for rear rail section.
15. Repeat step 12 for rear rail section.
16. Using special gauge-bar check level and alignment of rear rail section and tighten all nuts. A suitable gauge is illustrated on GMI drawing 222685-E.
17. Make a final alignment and level recheck on front rail using gauge wire or optical level. Check rear rail alignment and level using special gauge bar with front rail as reference.
18. Return installation dolly to tool dolly room side of elevator and load next two rail sections and pad templates with pads.
19. Repeat steps 6 through 16.
20. After both front and rear rails are completely installed, a last alignment check will indicate whether slight additional adjustment is required.

Note that when installing the reference wire or optical level, the system must be sighted parallel to the plane of the rear face. It is also assumed that the elevator will rise evenly without serious changes in levelness and that it travels in a plane parallel to the rear face. (These assumptions will permit leveling and alignment reference to the elevator itself.) With either method, the elevator should be initially checked for reproducible levelness using an optical level.

No attempt is made to estimate elevator rework, if any is required, nor is an estimate made here for dolly-room rework, or cable festooning.

ESTIMATE

Based on average time required for routine, non-regulated, contact maintenance procedures with a two man crew. Time (in hours) is total elapsed time for each operation.

Step	Crew Time Required	Repeat	Crew Total Time	Remarks
1	4	No	4*	*Not charged to installation costs.
2	Done by General Mills, Inc.			Part of RFM fabrication.
3	Done by General Mills, Inc.			Part of RFM fabrication.
4	2	No	2	
5	.1	6 times	.6	
6	.02	18 times	.4	Crew and dolly transit time only. Not included in calculation under Assumption 1 in sample calculation below.
7	4.	No	4.0**	**May not be required if wire can be left in place from step 1 above.
8	.25	12 times	3.0	
9	.1	12 times	1.2	
10	.25	12 times	3.0	
11	.25	6 times	1.5	
12	.3	6 times	1.8	
13	.5	6 times	3.0	
14	.25	6 times	1.5	
15	.3	6 times	1.8	
16	.5	6 times	3.0	
17	.5	No	5	
18	.02	18 times	.4	Crew and dolly transit time only. Not included in calculation under Assumption 1 in sample calculation below.
19				No time charge here.
20	.5	No	.5	

Time on Rear Face for regulated work.
See Assumption 1 on sample calculation.

27.4 hours

Add crew time on Rear Face for travel.
See steps 6 and 18 above.

.8 hours

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A sample calculation of the cost of installing the rails for the RFM may now be made. An example is given below.

Total elapsed time under normal, non-regulated contact maintenance is 27.4 hours:

Use 30 for calculations:

Assume 1) that 2 times as much time is required for this work, which must be done under SWP conditions,

$$2 \times 30 = 60.8 \text{ } \neq \text{ (.8 crew transit time)}$$

$$60.8 \text{ say } 61$$

Assume 2) working crew of two men (1 welder and 1 millwright) plus a RMU technician are required

$$3 \times 61 = 183 \text{ hours}$$

Assume 3) crews must be changed after 4 hours for 8 hour burn-out. Therefore, a total crew of $3 \times 2 = 6$ will keep three men on the rear face. Then,

$$6 \times 183 = 1,098 \text{ man hours to install}$$

Assume 4) \$7.00/man/hour including all burden and G & A charges

$$\$7.00 \times 1,098 = \$7,686$$

Assume 5) 25% Contingency Factor:

a. base cost from item 4	\$7,686
b. 25% addition for contingency	\$1,920

TOTAL	\$9,606
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DATE
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7/25/94

END