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SUPPLEMENTAL REPORT:

CONTROL OF HEAVY LOADS FOR SAN ONOFRE NUCLEAR GENERATING STATION UNITS 2 AND 3

Submitted to:

Southern California Edison
P. O. Box 800
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B-82-273

July 1982

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CONTROL OF HEAVY LOADS

RESPONSE TO NRC/EG&G REVIEW COMMENTS ON SONGS 2/3 SIX MONTH REPORT*

This supplemental report responds to comments contained in an EG&G Idaho, Inc. draft report dated April 1982. The comments were developed based upon a review of the SONGS 2/3 "6 month" report dated July 7, 1981, and subsequently clarified in a telephone conference among NRC, EG&G, TERA and SCE staff on June 17, 1982.

Comment 1. Cranes numbered 8 and 9, in Table 2.1 of EG&G's April 1982 report, were excluded from further evaluation. Confirm that loads handled by these cranes will only pass over redundant safe shutdown equipment that has been declared out-of-service.

Response

As stated on page 8 of SCE's July 7, 1981 report, the Diesel Building Cranes and Charging Pump Monorails service separate and individual trains of safety-related equipment and, by virtue of physical separation, a given crane cannot interact with both trains of equipment. Operating procedures will require any safety-related equipment potentially affected by lifts of over 1,500 pounds to be declared out of service prior to use of the Diesel Building Cranes or Charging Pump Monorails. Therefore, a load drop from either of the Diesel Building Cranes or Charging Pump Monorails would not result in damage to operable safe shutdown equipment.

Comment 2. Safe load paths are required for handling of all heavy loads, and must be included in approved procedures. Any deviations from these identified safe load paths must be approved by the plant safety review committee or its designated representative.

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* Additionally, errata to the Final Report, dated April 1982, are included in Appendix B to this Supplemental Report.

Response

Maintenance procedures will be revised to assure that permanent or temporary markings are used to indicate safe load paths for loads handled over safety-related equipment by plant cranes. The procedures will address all lifts of loads greater than 1,500 pounds that fall within the guidelines of NUREG-0612. Load handling procedures require that deviations from designated safe load paths will be approved, in writing, by the plant safety review committee or its designated representative. Safe load paths for monorails are defined by the monorail track and the width of the largest load to be handled by the monorail. Therefore, no loads wider than the specified safe load path width will be moved without prior approval, as indicated above.

Comment 3. All required documentation should be kept on file for the life of the plant.

Response

Drawings clearly identifying all crane locations and safe load paths will be maintained onsite while SONGS 2/3 are operational. In addition, load handling procedures will be retained on file and maintained up to date while SONGS 2/3 are operational.

Comment 4. Assure crane operator competence will be maintained and verified after initial qualification.

Response

Procedures are being developed which will require periodic (18 months) requalification of crane operators to ensure that they still meet the physical requirements of NUREG-0612, Section 5.1.1(3). If an operator previously designated as qualified is determined to no longer possess the requisite proficiency or physical qualifications, the procedures will require that appropriate steps be taken to assure that the identified deficiencies are corrected. Deficiencies that cannot be corrected may be sufficient reason for disqualification. Records on crane operator training, qualification and requalification will be documented and retained on file while SONGS 2/3 are operational.

Comment 5. Assure that crane interlocks or physical devices will not be overridden or bypassed without prior written authorization.

Response

Procedures (i.e., Station Order SO123-M-14) specifically prohibit overriding or bypassing interlocks and protective devices without specific authorization from the Maintenance Supervisor.

Comment 6. Justify why the Core Support Barrel Lift Rig, Turbine Rotor Lifting Beam and Contaminated Extension Yoke Assembly were not evaluated per ANSI 14.6-1978.

Response

None of the loads lifted by these lifting rigs is carried over fuel in the vessel, spent fuel or operable safe shutdown equipment. Specifically, the Core Support Barrel Lift Rig is used only when the reactor is shut down and fuel is removed from the vessel. As such, it does not carry loads over fuel or safe shutdown equipment required to be operable. Similarly, the Turbine Rotor Lifting Beam is used to service turbine rotors when the turbine is already out of service for maintenance repair. Lifts of the turbine rotor at this time do not involve movement over any safe shutdown equipment. The Contaminated Extension Yoke Assembly is used in lifts of the spent fuel cask. The cask pit is located at a sufficient distance from the spent fuel pool such that a potential drop of the cask would not interact with spent fuel.

Based on the above considerations, these lifting devices may be excluded from the scope of NUREG-0612 criteria related to ANSI N14.6-1978 evaluations.

Comment 7. Justify not evaluating the Reactor Vessel Head Lifting Rig and Upper Guide Structure (UGS) Lifting Rig as lifting "critical loads" under ANSI-N14.6-1978.

Response

The "Final Report - Evaluation of Heavy Load Handling Operations at San Onofre Nuclear Generating Station Units 2 and 3," dated April 1982, provides the basis for not classifying the reactor vessel head or UGS as a critical load. The evaluations and analysis results discussed in that report demonstrated that either the probability of a load drop was sufficiently small such that specific analyses of the consequences of the load drop were not necessary, or that the specific parameters of the load and handling operation were such that the analyses of the consequences of a load drop are to comply with the NRC NUREG-0612 evaluation criteria (i.e., NUREG-0612 Section 5.1).

Specifically, lifts of the reactor vessel head by the containment polar crane were analyzed on a probabilistic basis. (See Appendix A to this Supplemental Report for details of this analysis.) The results of the analysis indicated that the dominant failure mechanisms are those related to the occurrence of the head drop during its initial lift and hold from the reactor vessel flange. Since this initial lift is limited to one inch, the consequences of dropping the head at this stage of the lift are minimal and thus comply with NRC evalution criteria. For lifts subsequent to the initial lift and hold, the mean probability of failures leading to dropping of the head was determined to be on the order of 10^{-5} per lift, which is sufficiently small such that specific load drop consequence analyses are not necessary.

In the case of the UGS, specific analyses were performed for a postulated drop of the UGS onto the reactor vessel. The results of the analyses demonstrated that a drop of the UGS would not result in gross failure of the UGS, reactor vessel supports, or fuel in the reactor. Thus, it was demonstrated that the consequences of a postulated drop of the UGS acceptably comply with NRC evaluation criteria.

Based on the above load drop evaluations, it was determined that the reactor vessel head and UGS should not be classified as critical loads.

Comment 8. The stress design factors for the Reactor Vessel Head Lifting Rig and the UGS Lifting Rig should meet Section 3.2.1.1 of ANSI N14.6, including dynamic effects which would increase the maximum load.

Response

While the Reactor Vessel Head Lifting Rig and the UGS Lifting Rig were both designed and fabricated before ANSI 14.6-1978 was issued, the design of both lifting rigs was based on the ASME Boiler and Pressure Vessel Code and utilized good engineering practices and design conservatisms. In addition, in order to respond to NUREG-0612, we evaluated the stress design factors of the lifting rigs to determine the extent of compliance with the criteria of Section 3.2.1.1 of ANSI N14.6-1978. In our evaluation, both static and dynamic loads were considered.

The dynamic loads were determined in accordance with CMAA-70 Specifications, i.e., 0.5% of the load per foot per minute of hoisting speed. Both the reactor vessel head and UGS are lifted by the containment polar crane. The rated hoisting speed associated with these lifts is about 12 fpm. Therefore, an increase of 6% of the loads was included in the analyses to account for dynamic loads.

In general, lifting rod shear stresses, and support beam welds and bending stresses were found to be most critical. Nonetheless, the analyses indicated that the minimum safety factors for any load-bearing component in the Reactor Vessel Head Lifting Rig and the UGS Lifting Rig are generally greater than those specified in Section 3.2.1.1 of ANSI N14.6-1978. That is, the design stress factors exceed ANSI N14.6-1978 stress factor guidelines of 3 on yield strength and 5 on ultimate strength.

Based on the evaluations performed, it was concluded that considering both static and dynamic loads, the Reactor Vessel Head Lifting Rig and the UGS Lifting Rig designs meet ANSI N14.6-1978 Section 3.2.1.1 criteria.

Comment 9. Provide further justification for the adequacy of a 125% load test in lieu of the 150% load test required by Section 5.2.1 of ANSI N14.6-1978.

Response

The lifting rigs are subjected to initial NDE and periodic NDE as described in response to Comment 10. In addition to the justification provided on page 26 of our six-month report, the calculated dynamic load factor for these lifting devices is quite small (less than 6%) due to the slow speeds associated with the Containment Polar Crane. Additionally, load cells are used with both of these lifting rigs to ensure that reactor vessel components will not be subjected to additional loads as a result of load hangups. These load cells provide maintenance personnel an accurate indication of the loads to which these rigs are subjected and extend the same protective safeguards to the lift rigs.

Comment 10. Describe the NDE requirements for the Reactor Vessel Head and UGS lifting rigs in lieu of the 150% load test.

Response

ANSI N14.6-1978 provides that 150% load testing may be eliminated, and dimensional testing, visual inspection, and nondestructive testing of major load-carrying welds and critical areas shall suffice. As indicated in the discussion below, the Reactor Vessel Head and UGS lifting rigs will be subjected, prior to use during each refueling outage, to necessary visual, dimensional, and nondestructive examination. This will assure that any latent defects or deterioration will be detected.

Specific details of the visual, dimensional, and nondestructive examinations are provided in the following Tables 1 and 2. In general, however, the procedures will provide for the following:

(1) Visual and dimensional examinations of critical load bearing components, including lifting pins and bars, turnbuckles, support plates and cross bracings, etc. Visual examination shall be a thorough inspection

TABLE I

REACTOR VESSEL HEAD LIFTING FRAME ASSEMBLY

(Ref: Dwg E-234-320)

Part #	ITEM	VISUAL	DIMEN.	NDE PT	NDE MT	NDE UT
239-01	Lifting Frame Assembly consisting of:					
-03	Lug	x	x	x		
-04	Pipe & weldment to -03	x		x		
-05	Lifting eye & weldments	x	x	x		
-09	Lifting shackle	x	x	x		
-10	Clevis	x	x	x		
-11	Clevis	x	x	x		
-12	Lifting rod	x	x		x	x
-13	Recessed pin w/nuts	x	x			x
-14	Pin w/head & cotter pin	x	x			x
-15	Jam nut	x				
-16	Jam nut	x				

NOTES:

1. Dimen. check of parts -03, -05, -10, and -11 is for circularity of pin holes.
2. Dimen. check of Part -09 is for deformation of dimensions given in drawing details of the part (Ref: Dwg E-234-320).
3. Dimen. check of parts -13 and -14 is for warpage.
4. Dimen. check of Part -12 is for thread deformation. MT is at the threaded ends.

TABLE I
(CONTINUED)

ASSEMBLY OF RIG TO HEAD

(Ref: Dwg SO23-901-83-1)

Part #	ITEM	VISUAL	DIMEN.	NDE		
				PT	MT	UT
239-14	Pin w/head & cotter pin	x	x			x
241-08	Link assembly	x	x	x		
243-06	Lifting lug & weldment to -244-01	x	x	x		
244-01	Support skirt assembly including weldment of Part 243-02 (skirt) to Part 243-04 (Flange) Ref: Section view and Detail H	x		x		
240-09	Socket head cap screw	x	x			x
240-01	Box girder assembly & attachment to Part 241-08	x				
240-33	Platform support assembly and attachment to Part 241-08		x			
244-03	Instrument support ring & attachments to Part 244-01	x x				

NOTES: 1. Dimen. check of Part 239-14 is for warpage.

2. Dimen. check of Part 241-08 and Part 243-06 is for circularity of clevis pin holes.

3. Dimen. check of Part 244-09 is for elongation of cap screws, deformation of threads, and reduction in screw diameter.

TABLE 2

UPPER GUIDE STRUCTURE LIFT RIG TIE ROD ASSEMBLY

(Ref. Dwg SO23-904-2-1)

Dw. # - Part #	Item	Visual	Dimen.	NDE PT	NDE MT	NDE UT
E-STD-164-250-02	Plate	x	x	x		
-03	Clevis pin	x	x			x
-04	Soc hd cap screw	x				
-05	Plain washer	x				
-06	Lock plate	x				
-07	Pin	x	x		x	
-08	Spreader fitting assembly	x	x	x		
-09	Pins (3 each)	x	x			x
-10	Upper yoke (3 each)	x	x	x		
-11	Heavy hex jam nut (3 each)	x				
-12	Tie rod (3 each)	x				x
-13	Block (3 each)	x	x	x		
-14	Lock nut	x				
-15	Lock washer	x				
-16	Washer (3 each)	x				
-17	Cotter pin (3 each)	x				
-18	Heavy hex slotted nut (3 each)	x				
-23	Bushing	x				

Notes:

1. Parts -19, -20, -21, and -22 are welded together to form Part -08. Inspection of Part -08 includes weldments as well as the individual parts.
2. Dimen. check of parts -02, -08, -10, and -13 is for circularity of clevis pin holes.
3. Dimen. check of parts -03, -07, and -09 is for warpage of pins.

TABLE 2
(CONTINUED)

UPPER GUIDE STRUCTURE LIFT RIG SUPPORT STRUCTURE ASSEMBLY
(Ref. Dwg SO23-904-9-4)

Visually inspect of all connections and connecting members for damage, deformation, integrity of lock welds, and missing parts or loose connections.

UPPER GUIDE STRUCTURE LIFT RIG SPREADER ASSEMBLY
(Ref. Dwg SO23-904-17-0)

Dw. # - Part #	Item	Visual	Dimen.	NDE		
				PT	MT	UT
E-STD-164-257-02	Special channel (welds)	x				
-03	Special channel (welds)	x				
-04	Special channel (welds)	x				
-05	Channel	x				
-06	Yoke & weldment to -02	x	x	x		
-07	Bar & weldment to -02	x				
-08	Butt hinge & weldments	x				
-09	Block & weldment to -02	x				
-10	Pin	x				

Notes: Dimen. check of Part -06 is for circularity of hole for pin and dimen. from center of yoke pin hole to center of spreader assembly (typical 62.750 inch at 3 places).

TABLE 2
(CONTINUED)

UPPER GUIDE STRUCTURE LIFT RIG ASSEMBLY DETAILS

(Ref. Dwg SO23-904-13-1)

Dw. #	Part #	Item	Visual	Dimen.	NDE PT	NDE MT	NDE UT
E-STD-164-258	-03	Handle	x				
	-04	Hex head bolt	x				
	-05	Hook	x				
	-06	Lifting bolt	x	x			x
	-07	Dowel pin	x				
	-08	Tube	x				
	-09	Tube	x				x
	-10	Collar & weldment to -09	x		x		
	-11	Base	x				x
	-12	Plate	x				
	-13	Plate	x				
	-14	Plate	x				
	-15	Plate & weldment to -09	x		x		
	-16	Pin	x	x			x
	-18	Plate	x				
	-19	Plate & weldment to -10	x		x		
	-20	Plate & weldment to -21	x				
	-21	Pipe	x				

NOTES: 1. Dimen. check of Part -06 is for deformation of threads, elongation of bolt shank and reduction in diameter of shank.

2. Dimen. check of Part -16 is for warpage.

TABLE 2
(CONTINUED)

UPPER GUIDE STRUCTURE LIFT RIG SLING ASSEMBLY

(Ref. Dwg SO23-904-10-2)

Dw. # - Part #	Item	Visual	Dimen.	NDE		
				PT	MT	UT
E-STD-164-259-06	Bolt	x	x	x		
-08	Shackle	x	x	x		
-10	Bar	x	x	x		
-11	Cable assembly	x	x	x		
-12	Bolt	x	x	x		

Notes:
1. Dimen. inspection of parts -08, -10 and -11, is for circularity of pin holes in each of these parts.
2. Dimen. inspection of parts -06 and -14 are is for reduction in bolt shank diameter.
3. Inspection of Part -08 includes the shackle pin bolt (dimen. inspection of bolt for warpage).
4. Inspection of Part -11 shall be according to ANSI B30.9-1971, Slings, with added DT inspection of sling eyes and pins and dimen. inspection of sling eyes for circularity and pins for warpage.

TABLE 2
(CONTINUED)

UPPER GUIDE STRUCTURE LIFT RIG PICKUP ADAPTOR

(Ref. Dwg SO23-904-19-0)

Dw. # - Part #	Item	Visual	Dimen.	NDE		
				PT	MT	UT
E-STD-164-261-01	Pickup adapter assembly consisting of:					
-02	Bar	x	x	x		
-03	Bar	x		x		
-04	Gusset	x		x		
-05	Tube	x		x		
-06	Tube	x		x		
-08	Nut	x		x		
-11	Base	x		x		
-12	Pickup bolt	x		x		

Notes: 1. Dimen. inspection of Part -02 includes the screw pin holes for attaching the sling assemblies. Dimen. check of pin holes for circularity.

2. DT inspection of all part weldments to matching parts.

for deterioration, corrosion, or deformation. Dimensional examinations shall be made for warpage, for circularity of pin holes, and for reduction in cross-sectional area, as appropriate.

(2) Inspections utilizing liquid penetrant or magnetic particle examination shall be performed using written procedures and personnel, both qualified per the rules in the ASME Boiler and Pressure Vessel Code, Section V, Articles 1, 6, 7, 24, and 25.

(3) Liquid penetrant and magnetic particle acceptance standards shall be as indicated in paragraphs NF-5350 and NF-5340 of the current edition of the ASME Boiler and Pressure Vessel Code, Section III, Division 1.

Comment 11. Provide a more detailed comparison with Section 3.1, Section 3.3 and Section 4.1 of ANSI N14.6-1978.

Response

Comparisons of design and fabrication of the Reactor Vessel Head and UGS lifting rigs to the subject ANSI N14.6-1978 sections are provided below.

Section 3.1 Designer's Responsibilities - Our review of the designer's equipment manual and design documents indicates that sound engineering practices were specified by the designer for the fabrication of the Reactor Vessel Head and UGS lifting devices, including selection of structural materials, fabrication practices, in-process testing and inspection. The designer's equipment manual provides an adequate guide to the user for the proper use of the device. We judge these documents to be an acceptable fulfillment of the designer's responsibilities for this section (3.1) of the standard. While procedures in effect at the time of the lift rig's design did not require formal design documentation, the designs were performed in accordance with the 1971 edition of the ASME Boiler and Pressure Vessel Code, Section III, Article NB-3000. While the designer's stress analyses are not available for review, we have performed an evaluation to assure that appropriate margins of safety exist. This evaluation is described in Response to Comment 8 herein. Also, maintenance and repair procedures, while not available from the designer, have been developed and approved for use at SONGS 2/3.

Section 3.3 Design Considerations - Our review of the design of both lifting rigs indicates that sound design concepts were applied even though the designs preceded the existence of the standard. The materials selected are sound and inspection prior to each use and other NDE will be used to detect potential or actual problems. For example, corrosion concerns in Subsection 3.3.2 will be effectively alleviated by periodic visual inspections. The Reactor Vessel Head lifting rig does not rely on remote engagement devices. The UGS lifting rig does meet these remote engagement criteria (Subsection 3.3.3). The lifting devices are designed to assure distribution of load to all load-bearing members, and load-carrying components that may become inadvertently disengaged are fitted with cotter pins. The large size of the lifting devices prevents problems with recovery should they become unintentionally disengaged.

Section 4.1 Fabricator's Responsibilities - The general intent and many of the specific responsibilities discussed in this section were placed upon the fabricator by the design drawing requirements and specifications. The approved designer drawings and specifications specify ASTM and other industry standard material and mechanical requirements, including tolerances and fabrication practices. The quality of radiographic testing was to be in accordance with ASTM A451-72, SP1-9R. Finally, the quality of the fabrication process was demonstrated by means of material and component acceptance tests, examinations, and certifications.

Comment 12. Working loads for slings should correspond to the sum of static and the maximum dynamic loads. Additionally verify that the sling marking requirements of ANSI B30.9 and NUREG-0612 Section 5.1.1(5) are met.

Response

With regard to the lifts identified, which utilize slings, plant procedures will require that sling selection, use, and marking will be in accordance with ANSI B30.9 and NUREG-0612 Section 5.1.1(5). Rated loads identified for each sling will be based on the sum of the static and maximum dynamic load. Dynamic loads have been determined in accordance with CMAA-70 specifications, i.e., the dynamic load "shall be taken as ½% of the load per foot per minute of hoisting speed." The maximum hoist speeds are for the polar and turbine gantry cranes, and at no load would be 15 fpm. This would result in a maximum dynamic load of 7½% of the lifted load. Therefore, the plant procedures will specify that, as a minimum, sling selection be based on 110% of the lifted load.

Comment 13. Indicate whether the applicable sections of ANSI B30.2 and CMAA-70 are met for the Polar Crane.

Response

The Polar Crane has been compared to both CMAA-70 and Section 2-1 of ANSI B30.2-1976. All applicable criteria which would affect load handling reliability were determined to be complied with.

Comment 14. Provide the level of proof loading for monorail hoists.

Response

All monorail hoists were proof tested at 150% of rated load prior to delivery as part of the manufacturer's standard practice.

Comment 15. Provide more detailed description of the probabilistic evaluation of the reactor head drop.

Response

Appendix A presents a report describing the Reactor Vessel Head Drop Analysis.

APPENDIX A

SONGS 2 AND 3
REACTOR VESSEL HEAD
DROP ANALYSIS

TERA CORPORATION

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1.0 INTRODUCTION

The United States Nuclear Regulatory Commission in Report NUREG-0612, "Control of Heavy Loads at Nuclear Power Plants," proposes guidelines which control movement of heavy loads (Reference 1). Accidental drops of heavy loads which could damage spent fuel, cause criticality accidents, or damage safe shutdown equipment are required to be evaluated in accordance with NUREG-0612 guidelines.

One operation of interest, because of potential interactions with the reactor core, is the handling of the reactor vessel head during refueling operations. NUREG-0612 requires that the probability of dropping the head be small or that the consequences for dropping the head be within acceptable limits (see page 5-1 of NUREG-0612).

This analysis deals with a failure analysis of the polar crane system at San Onofre Nuclear Generating Units 2 and 3 during refueling, when the reactor head is being removed and installed. Consistent with the overall basis for establishing the level of safety associated with the guidelines described in NUREG-0612, Fault Tree Analysis (FTA) has been used to address all the ways by which the polar crane system, including rigging, could fail and lead to a drop of the reactor vessel head. The limits of resolution in FTA are <u>basic events</u> which include for this study:

- o Human error events (e.g., crane operator failure, erroneous test and maintenance actions)
- o Equipment failure (e.g., structural failure, control system failures leading to overspeed).

Combinations of basic events that insure occurrence of the Top Undesired Event are called <u>min cut sets</u>, also known as system failure modes. For this study, min cut sets describe possible events which could lead to a drop of the reactor vessel head during refueling. To accomplish the FTA, sources of data for the basic events must be located so that the probability of a drop of the reactor head occurring during refueling can be computed. The sources for this study include plant data, data from crane manufacturers, Navy and OSHA data regarding crane failures and licensee event reports. By ranking basic events and min cut sets by their contribution to the system failure probability, it was possible to establish the dominant basic events and min cut sets.

The organization of this report follows the step-by-step procedure by which the fault tree is generated and analyzed. These steps include:

- Description of the polar crane system and associated testing, maintenance, inspection, training and lift procedures regarding reactor head removal and installation during refueling

- Events identification and fault tree construction -- determine possible ways the polar crane system could fail

  (1) Structural failure while subjected to normal load conditions

  (2) Structural failure due to excessive load

    - Two-blocking event
    - Load hangup event

  (3) Overspeed event -- loss of hoisting or lowering capability coupled with loss of brakes

- Qualitative analysis -- find min cut sets and establish all single failure events leading to system failure

- Probabilistic analysis

  (1) Identify sources of data applicable to San Onofre operations

  (2) Compute probability of the Top Event

  (3) Probabilistically rank basic events and min cut sets (i.e., conduct a sensitivity analysis)

2.0 SUMMARY OF RESULTS

For heavy load drop events, NUREG-0612 suggests that a total probability of 10^{-6} per reactor year or less is within acceptable limits. Recent ACRS (Reference 2) and NRC staff (References 3 and 4) positions on quantified safety goals indicate that a more reasonable level of total probability for core melt is 10^{-4} to 10^{-5} per reactor year. It should be emphasized that the accident analyzed here would not likely result in core melt and, in any event, the decay heat and fission product inventory reduction due to shutdown is such that the consequences of any load drop accident would be less severe than those of a core melt accident.

The FTA addressed two individual events: drop of the reactor vessel head during removal and drop of the reactor vessel head during installation. These two events generate the same load drop scenarios with two exceptions:

- During installation, a two-blocking event would most likely occur above the reactor head laydown area. Hence, this scenario is not considered during installation.
- A reactor head load hangup event over the vessel could only occur during removal. Again, this scenario is not considered during installation.

During head removal operations, the head is initially lifted one inch above the reactor vessel flange and carefully inspected. The head remains suspended in that position for 15 minutes before further lifting. To account for these operations, the analysis was segregated into two types of potential load drops:

- Drop during initial lift
- Drop after head clears alignment pins.

A drop during initial lift could result from either a load hangup event or structural failure. Such a drop would occur at a height of no more than one inch above the flange and is of no safety significance. The probability of a structural failure or load hangup following this initial lift is significantly reduced.

The results of the analysis indicate that the dominant failure mechanisms are those related to the occurrence of a load drop during its initial lift and hold from the reactor vessel flange. The mean probability of such an occurrence was determined to be on the order of 10^{-4} per lift. Because the initial lift height is limited to one inch above the flange, the consequences of dropping the head at this stage of the lift are considered minimal. The mean probability of failures leading to dropping of the head subsequent to the initial lift and hold was determined to be on the order of 10^{-5} per lift, which is sufficiently small to assure that adequate safeguards are provided by the equipment and procedures used for this lift at SONGS 2/3. Specific analyses of the consequences of a load drop are not necessary. Based on the results of the analysis and the further actions being undertaken, it is concluded that reactor vessel head lifting operations will be conducted safely.

3.0 SYSTEM DESCRIPTION

During refueling, which occurs approximately every 18 months, the reactor vessel head is removed and placed in an area inside the containment building called the reactor vessel head laydown area. As shown in Figures 1 and 2, the head is moved in straight, obstruction-free paths for both removal and installation of the head. Procedures governing reactor vessel head removal and installation are given in References 5 and 6.

The crane which lifts, moves, and lowers the reactor head is an overhead gantry crane on circular rails called a polar crane (see Figure 3). The link assembly on the reactor head is attached to the hook on the main hoist of the polar crane by the reactor head lifting device. The polar crane consists of a bridge that spans the entire radial distance of the containment at an elevation of 120 feet above the floor of the containment. The bridge moves either clockwise or counterclockwise on a circular rail on the circumference of the containment building. The trolley moves horizontally on the bridge. Affixed to the trolley are the main and auxiliary hoisting system which consists of a drum, cabling, a fixed upper block and a lower block that moves vertically upward or downward depending upon the rotation of the drum. Attached to the lower block is the main hook.

For the reactor vessel head lift, the crane operator controls movement of the crane from the cab, which is located at the end of the bridge. There are three separate master switch levers in the cab for movement of the hoist, trolley and bridge. To move the master switch hoist lever requires that the "OFF" position latch on the master switch be pressed. Moving the master switch handle away from the operator will lower the main hook at speeds proportional to the amount of handle movement. Moving the handle in the opposite direction will raise the main hook. The maximum speed of the hook at full load conditions is 8.4 fpm.

A block-operated overhoist limit switch will trip at the uppermost position to stop hoisting and set both brakes on the hoisting drum. Contacts on a rotary

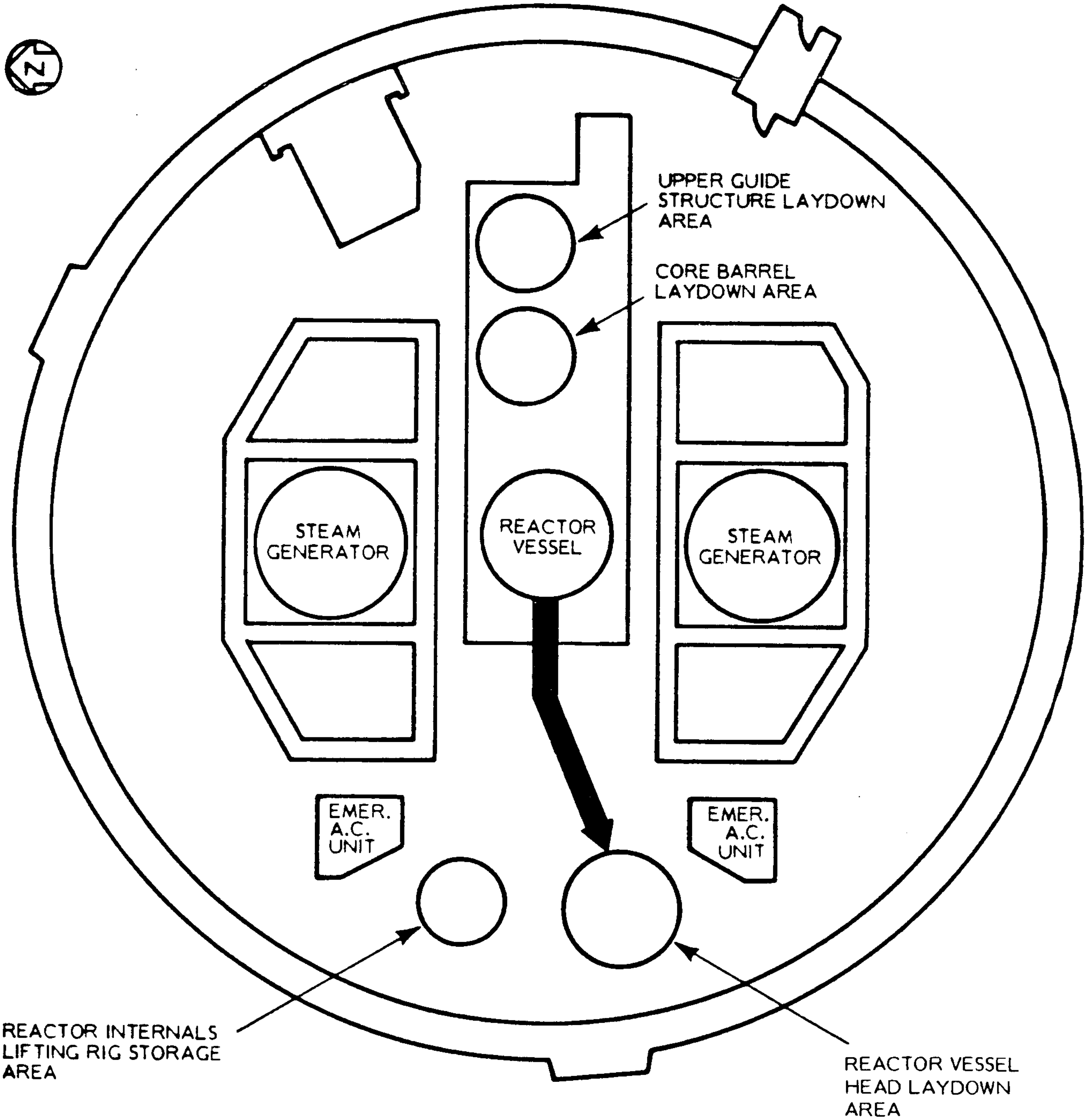

FIGURE 1

PATH FOR REACTOR HEAD REMOVAL

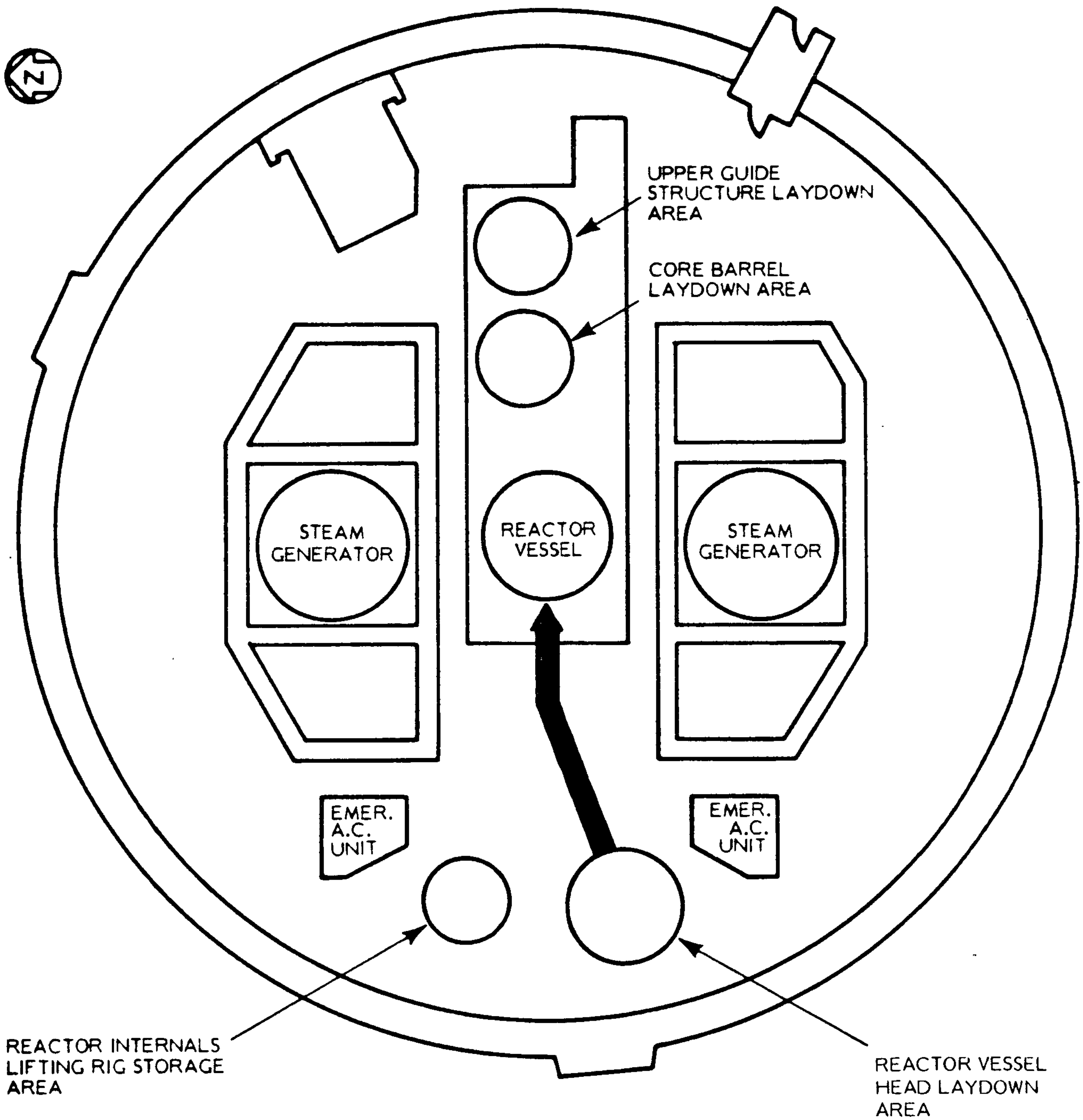

FIGURE 2

PATH FOR REACTOR HEAD INSTALLATION

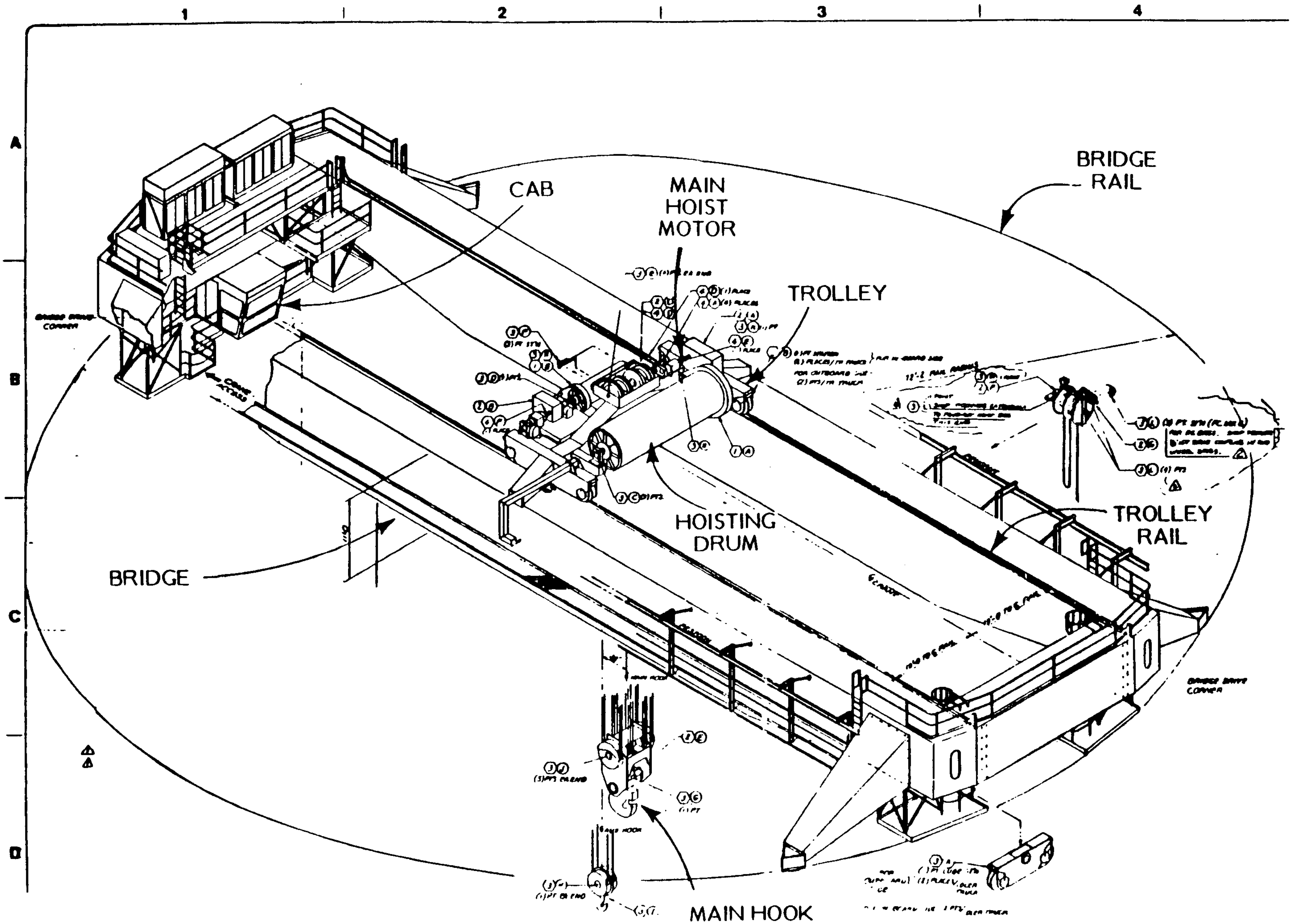

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FIGURE 3

POLAR CRANE

limit switch, coupled to the drum, will trip at the extreme lowered position. To hoist or lower out of a tripped limit switch requires movement of the master switch lever in the opposite direction.

The hoist drive is equipped with an overspeed switch set to trip at a motor speed of 3,200 rpm to stop the drive and set the brakes. Placing the master switch in the "OFF" position sets the brakes. A detailed description of the operation of the polar crane is given in Reference 7. A General Electric MAX-SPEED 250 Control System is used for speed control of the hoisting system limiting no-load speeds to approximately 250 percent of full-load speeds. The hoisting motor is powered by a DC generator that is in turn powered by an AC motor. The speed and direction of the hoisting motor are controlled by the MAX-SPEED 250 Control System, which also includes the limit switches, brakes, and emergency stop circuit. The system information was included in the fault tree.

Prior to operating the polar crane for movement of heavy loads, a preoperational checkout procedure is performed. The wire rope, main hoisting hook, and the hoisting drum are all inspected. Tests of the brakes are performed as well as tests for the operation of the upper limit switch. In addition, the load cell, which is used during lift, is calibrated by lifting a load of a known weight. The checkout procedure is described in detail in Reference 7.

In addition, procedures require that the reactor vessel head lifting device be inspected prior to its use during refueling.

For head removal, the main hook is directly engaged to a load cell. The load cell is a steel pin provided with strain gauges which fits into the linkage of the reactor head lifting device. The lifting device is centered over the reactor vessel head and lowered to mate with three eyes on the head lifting fixture link assembly (permanently mounted on the vessel head). Three pins are manually secured and lock nuts positioned. The reactor vessel head is lifted one inch and carefully inspected. The head remains suspended at the initial lift position until the inspection of lifting equipment is complete. During all lifting operations a second operator on the refueling floor reads the load cell as the head is lifted. The load cell and second operator are included to detect load hangups which could result in equipment overstresses and are independent of NUREG-0612 considerations. An excessive load cell reading will cause the second operator to signal the crane operator to stop lifting. After the head is lifted to its required height, it is moved horizontally away from the reactor vessel. The head is then further lifted and moved to the reactor head laydown area.

4.0 EVENTS IDENTIFICATION AND FAULT TREE CONSTRUCTION

A fault tree with Top Event, "Drop of Reactor Vessel Head During Refueling," was constructed. Specifically of interest is the probability of possible drops which could occur above the reactor vessel at a free field distance greater than the initial one-inch lift.

As indicated in Section 1.0, a drop of the reactor head could occur in three basic ways:

- o Structural failure while subjected to normal load conditions
- o Structural failure due to excessive loads
- o Overspeed event — loss of hoisting or lowering capability coupled with loss of brakes.

With regard to structural failure, the polar crane system, including rigging, is a series system which includes the following:

- o Bridge, trolley, hoisting drum, cable, gears, shaft and hook
- o Load cell
- o Link assembly on reactor head (considered generically as rigging for this study)
- o Reactor head lifting device.

Excessive loads on cabling could occur if the movable lower block touches the upper block, called a two-blocking event. In this case, mechanical advantage would be lost resulting in excessive load. Another way excessive cable load could be experienced is by attempting to lift a load that is stuck in place.

The head could also be dropped by loss of hoisting capability during lifting <u>or</u> by loss of lowering capability <u>coupled</u> in both cases by loss of brakes. The braking system for the hoisting motor consists of two redundant brakes which activate when their respective solenoids are de-energized (i.e., fail safe upon loss of power). In addition, there is a dynamic brake as a backup. Upon loss of power, the hoisting motor field self-excites and energy is dissipated by discharging electrical current through a dynamic brake resistor, preventing free fall of the lifted load.

The Top Event to the fault tree is defined in terms of two events:

- o Drop during removal
- o Drop during installation.

These two events generate the same load drop scenarios with two exceptions:

- o During installation a two-blocking event would most likely occur above the reactor head laydown area. Hence, this scenario is not considered during installation.
- o A reactor head load hangup event over the reactor vessel could occur only during removal. Again, this scenario is not considered during installation.

The fault tree is further segregated into two types of drops:

- o Drop during initial lift
- o Drop after head clears alignment pins.

Potential drops during initial lift include load hangups and structural failures. These drops are of little consequence because they would be from a height of one inch or less. They are considered separately in the probabilistic analysis.

The probability of structural failures was also analyzed for the time period <u>after</u> the head clears the alignment pins. This means a component would have to fail after having sustained load for at least 15 minutes. Such a condition is highly unlikely for a ductile steel structure. As described in Section 6, probabilities for these events were assigned in terms of conditional probabilities.

The fault tree also included two events other than structural failures:

- o Overspeed events
- o Two-blocking events.

The fault tree development considered the following sequence of events which must occur for two-blocking:

- o Hoisting motor continues to operate above upper limit switch position (due to error of the crane operator and second operator or to equipment failure)
- o Limit switch failure (equipment failure).

Another type of two-blocking event was considered which involves reverse reeving. For reverse reeving to occur, the cabling must be completely unwound and then rewound backwards around the drum. Therefore, for two-blocking to occur with reverse reeving, the following sequence of events has to occur prior to the two-blocking sequence described above:

- o Failure of the lower limit gear-operated limit switch
- o Failure by the operator to notice that a complete rewinding of the cable has occurred.

We consider a reverse reeving event to be at least 100 times less likely than a two-blocking event due to the additional two failures which must occur in sequence with two-blocking. For this reason, a reverse reeving event was not developed on the fault tree.

For a load hangup event to occur the following sequence of events must occur:

- o Reactor head is initially stuck in place
- o Hoist motor continues to operate
- o Hoist brakes fail to operate

- o Handling system failure given load hangup (assumed to occur with probability one).

It is assumed in the above case that the crane system could not lift the reactor head with the brakes set (other failures must occur for the hoist motor to operate simultaneously with the brakes set).

Several events must occur simultaneously to initiate an overspeed condition:

- o High generator voltage (caused by failure of either the generator feedback circuit or resistor)
- o Low motor field (caused by failure of the field strengthening circuit)
- o Loss of either the hoisting motor, DC generator, AC generator or AC power.

Because there is a different circuit response depending upon which event initiated the overspeed condition, a different fault tree is constructed for each initiating event.

For a drop of the head to occur during overspeed, the braking system on the hoist motor must fail. Because all three brakes are entirely redundant, all three brakes must fail, which is considered highly unlikely.

5.0 QUALITATIVE EVALUATION

The fault tree was coded according to descriptor events in such a manner that each min cut set will contain one or more events that describe the type of load drop scenario. These events are listed below:

- Structural failure during initial lift
- Structural failure after initial lifting
- Drop of head during initial lifting
- Reactor head load hangup event
- Overspeed event
- Two-blocking event.

The computer code FTAP (Reference 8) was used to find the min cut sets. A total of 96 min cut sets were found. Eight min cut sets of order 1 were obtained (disregarding descriptor events). Order refers to the number of basic events in the min cut sets. These eight min cut sets are structural failures that occur either during or after initial lifting. A table of the number of min cut sets versus order is given below:

Order	1	2	3	4	5
No. of Min Cut Sets	8	0	18	38	32

Again, descriptor events are not considered in the above table.

6.0 PROBABILISTIC ANALYSIS

The probabilistic or quantitative analysis was conducted in three steps for this study:

- o Evaluating probabilistic data for basic events
- o Computing the probability of the Top Event (i.e., probability of reactor head drop during refueling)
- o Determining the most important basic events and min cut sets that contribute to the load drop event (i.e., conducting a sensitivity analysis).

Each step is discussed below.

6.1 PROBABILISTIC DATA FOR BASIC EVENTS

The basic event data needed for the probabilistic analysis were compiled. The method by which the probability is computed is described by the type of failure (e.g., demand failures, conditional probabilities). The uncertainty in the estimate is given by the error factor. For a lognormal distribution, the error factor is defined in such a manner that the probability times the error factor is the upper 90 percent confidence limit estimate for the basic event probability.

The data used were for three types of events:

- o Structural failure
- o Human error
- o Equipment failure.

6.1.1 STRUCTURAL FAILURES

As described in Section 5.0, there are eight min cut sets involving structural failure. These failures include:

- o Structural failure of the polar crane system
- o Structural failure of the reactor head lifting device
- o Structural failure of the load cell
- o Structural failure of the link assembly on the reactor vessel.

These failures apply both to initial lifting and to lifting after the head clears the alignment pins. The basic starting point for obtaining data for the above failures was to examine NUREG-0612. Section 4.2 of that report compiled data for crane failures involved in U.S. Navy operations. A total of 43 load drop events occurred between February 1974 and October 1977. NUREG-0612 estimated that the number of lifts which occurred is between 2.5×10^5 and 1.5×10^6 with an estimated midpoint at 8.75×10^5 lifts. In addition, NUREG-0612, as shown in Table 1, categorized the 43 load drop events according to the cause of failure:

- o Crane failure
- o Crane operator failure
- o Rigging.

A <u>conservative estimate</u> for the probability of structural failure for the polar crane would result by using the data given in Table 1. However, maintenance and operational procedures at nuclear power plants impose much stricter requirements than do Navy procedures. For this reason, we assume that the <u>best estimate</u> for the probabilities in Table 1 as applied to San Onofre operations would be reduced by 0.5 (as was assumed in NUREG-0612).

TABLE I

CAUSES OF CRANE ACCIDENTS

U.S. DEPARTMENT OF THE NAVY

Cause Category	(1) Number of load drop events reported	(2) Upper bound estimate*	Estimated** mean probability
1. Crane failure	10	20	1.7×10^{-5}/lift
2. Crane operator failure	30	60	5.1×10^{-5}/lift
3. Rigging failure	3	6	5.1×10^{-6}/lift
Total	43	86	7.4×10^{-5}/lift

* Assumes only one-half of the events are reported.

** Calculated as the average of columns (1) and (2) divided by the estimated mean number of lifts, 8.75×10^5.

In addition, we gave credit to the procedure that requires the vessel head to be suspended for 15 minutes. We assumed that structural failure occurring after this period to be a factor of 5 less than that during the initial lifting period.

6.1.2 HUMAN ERROR

We assumed the occurrence of the first operator error in a min cut set to be 10^{-2}/event with an error factor of 10. This is consistent with WASH 1400 assumptions. In addition, in some cases we assumed crane operator error to be completely coupled (i.e., completely dependent in a statistical sense) with the occurrence of the first operator error. For example, we assumed that, in a load hangup event or a two-blocking event, the operator would fail, with probability one, to press the emergency stop, given that he failed to put the main hoist master switch in the stop position.

6.1.3 EQUIPMENT FAILURE

Two types of equipment failure are considered in this study:

- Being unavailable at the time of the demand (e.g., open or short circuit in a control circuit)
- Failure to change state upon demand (e.g., relay contacts failing to open, brakes failing to operate).

In the first case, the failure probability is an integral over time. In all cases except one, testing the polar crane prior to operation insures that the control circuitry in the MAXSPEED 250 control system is working at the start of the lift. The exposure time or fault duration time for failure to occur is five hours, a conservative estimate of the time required to remove the reactor head. However, procedures do not require testing the dynamic brake resistor. In this case, we assume an exposure time of one-half of the expected plant life, which is 15 years, a time which is necessary in computing average unavailability or average probability of not working.

In all cases, except two, we used data from WASH 1400. For brake failures, we used the Navy data in Table 2 and conservatively assumed for probability estimation that all crane failures were due to brake failures. Hence we assigned a probability of 1.7×10^{-5}/lift for failure of one brake. However, the hoisting motor has two redundant brakes. Procedures called for testing the brakes prior to lift but do not call for testing the brakes individually. For this reason we assumed a coupling probability of 0.1 for failure of the second redundant brake, given failure of the first.

For the dynamic brake resistor failing open circuited, we used the UKAEA data which is 1.0×10^{-6}/hr.

6.2 PROBABILITY OF REACTOR VESSEL HEAD DROP

We used the computer code IMPORTANCE (Reference 9) to compute the probability of reactor vessel drop per lift. We used the basic event data and assumed the human error events and hardware failure events, as described in the last section, to be coupled; otherwise basic events were assumed to be statistically independent. The results are presented in Table 2 assuming one lift per 18-month period between refuelings. The conservative estimate in Table 2 assumes that Navy data are directly applicable for structural failures of the polar crane. The best estimate uses the Navy data but with a reduction of 0.5 to allow for improved maintenance and operational procedures.

6.3 SENSITIVITY ANALYSIS

We use the concept of probabilistic importance to rank basic events and min cut sets according to their quantitative contribution to the Top Event probability.

TABLE 2

REACTOR HEAD DROP PROBABILITY PER YEAR

	Best Estimate	Conservative
Including Initial Lift	9.7×10^{-5}	1.3×10^{-4}
Excluding Initial Lift	5.6×10^{-6}	8×10^{-6}

In this study, the Top Event probability is small and can be accurately approximated by the sum of the min cut set probabilities, stated mathematically,

$$\text{Prob. of the Top Event} = \sum_{j=1}^{N} \prod_{i \epsilon k_j} q_i$$

where q_i = probability basic event i is occurring

$i \epsilon k_j$ means for all basic events contained in min cut set k_j

j is an index for the min cut sets

N = number of min cut sets (288 for this study)

where it is assumed that basic events are statistically independent. In the case of coupled probabilities, conditional probabilities must be used in the above expression.

In addition, we can define the importance of basic event i, I_i, as the ratio of the sum of the min cut sets containing basic event i to the Top Event probability. Stated mathematically,

$$I_i = \frac{\sum_{j} \prod_{\substack{\ell \epsilon k_j \\ i \epsilon k_j}} q_\ell}{\text{Prob. of the Top Event}}$$

For example, if a basic event is contained in every min cut set, then its importance value is unity. These measures are computed by IMPORTANCE.

The events for the best-estimate case which includes the initial lift were ranked by importance value. By simply taking the importance value times the Top Event probability, we get probabilities of various load drop scenarios, as shown in Table 3.

TABLE 3

MEAN PROBABILITIES OF VARIOUS LOAD DROP SCENARIOS PER LIFT (BEST ESTIMATE CASE)

Load Drop Scenario	Mean Probability
o Drop of head during initial lift	1.2×10^{-4}
- Reactor head load hangup event	1.0×10^{-4}
- Structural failure during initial lift	1.6×10^{-5}
o Drop of head after initial lift	8.4×10^{-6}
- Two-blocking event	5.2×10^{-6}
- Structural failure after initial lift	3.2×10^{-6}
- Overspeed event	4.3×10^{-9}

7.0 REFERENCES

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7. Polar Crane Checkout and Operation, San Onofre Nuclear Generating Station, Maintenance Procedure SO23-1-3.22.

8. Willie, R., Fault Tree Analysis Program, Operations Research Center Report ORC 78-14, University of California, Berkeley, 1978; Report UCRL-73981, Lawrence Livermore National Laboratory.*

9. Lambert, H. E. and B. J. Davis, The Use of the Computer Code IMPORTANCE with SETS Input, Sandia Report SAND81-7068, U.S. Nuclear Regulatory Commission, Report NUREG/CR-1965, 1981.*

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* Available from National Technical Information Service, Springfield, VA 22151, USA.

APPENDIX B

ERRATA TO

CONTROL OF HEAVY LOADS FOR SAN ONOFRE NUCLEAR GENERATING STATION UNITS 2 AND 3

FINAL REPORT

April 1982

Page 3-14 The section under AFW Pump Bridge Crane should read as follows:

"Lifts of pump motors and pump components above an operating pump will be restricted to such times as the plant is in cold shutdown."

Table 3-5 The Hazard Elimination Category should read as follows:

"Administrative controls will be implemented to restrict lifting of pump motors and pump components above an operating pump to such times as the plant is in cold shutdown."