NUS-3495

THE FEASIBILITY OF RETRIEVING NUCLEAR HEAT SOURCES FROM ORBIT WITH THE SPACE SHUTTLE

Prepared for

THE UNITED STATES DEPARTMENT OF ENERGY

Advanced Nuclear Systems and Projects Division

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1.0 INTRODUCTION AND SUMMARY

Spacecraft launched for orbital missions have a finite orbital lifetime. Current estimates for the lifetime of the nine nuclear powered U.S. satellites now in orbit range from 150 years to 10^6 years. Orbital lifetime is determined primarily by altitude, solar activity, and the satellite ballistic coefficient. There is also the potential of collision with other satellites or space debris, which would reduce the lifetime in orbit.

These orbiting power sources contain primarily Pu-238 and Pu-239 as the fuel material. Pu-238 has an approximate 87-year half life and so considerable amounts of daughter products are present after a few tens of years. In addition, there are minor but possibly significant amounts of impurity isotopes present with their own decay chains.

Radioisotopic heat sources have been designed to evolving criteria since the first launches. Early models were designed to burn up upon reentry. Later designs were designed to reenter intact. After tens or hundreds of years in orbit, the ability of any oribiting heat source to reenter intact and impact while maintaining containment integrity is in doubt. Such ability could only be verified by design to provide protection in the case of early mission failures such as launch aborts, failure to achieve orbit, or the attainment of only a short orbit.

With the development of the Space Shuttle (Space Transportation System) there exists the potential ability to recover heat sources in orbit after their missions are completed. Such retrieval could allow the risk of eventual reentry burnup or impact with atmospheric dispersion and subsequent radiation doses to the public to be avoided.

The purpose of this study is to evaluate the feasibility and the limitations inherent in using the Space Shuttle for recovery of radioisotopic heat sources in orbit.

Section 2.0 of this report contains descriptions of the capabilities of the Space Shuttle and the Remote Teleoperator system (RTS) to rendevous with existing orbiting RTGs. Only LES 8 and 9 are beyond the reach of the planned capabilities of these systems. A problem is identified relative to the acquisition of tumbling or spinning satellites. Section 3.0 presents current criteria for crew radiation dose in space missions.

Section 4.0 discusses, in general terms, the mission-specific evaluations that will be needed as part of the preparation for retrieval. Section 5.0 presents a rough cost estimate for a retrieval mission, which is likely to be comparable to a launch mission, including planning, hardware design and fabriction, and safety assessments, as well as the cost of the acquisition system, including an RTS, if needed.

During the conduct of this work, the following organizations and persons were consulted; however the conclusions and observations made are those of the authors.

Martin Marietta Corporation
Denver, Colorado
Contacts: Richard Spencer
William Britton

Johnson Space Center
Houston, Texas
Contacts: Harold Benson
Reuben Taylor
Donald Kessler

Marshall Space Flight Center
Huntsville, Alabama
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2.0 RETRIEVAL TECHNOLOGY

2.1 Spacecraft Containing Nuclear Heat Sources

Approximately 5000 spacecraft are presently in earth's orbit and more than 6000 have reentered the atmosphere.(1) Only 9 spacecraft launched by the United States for orbital missions contain nuclear power supplies. None have ever reentered from orbit.

A summary of the spacecraft with nuclear power supplies is presented in Table 1. As can be seen, most of these have orbital lifetimes of a thousand years or more, the exceptions being "Transit" (TRIAD 0I-1X), with a 150-year orbital lifetime and Transit 4A, which has a 570-year orbital lifetime. The LES-8 and 9 spacecraft, which have the highest Pu-238 inventory, are in geosynchronous orbit and have an orbital lifetime approaching infinity.

It should be noted that orbital lifetimes presented in Table 1 are based on decay of the orbit caused by atmospheric drag. A recent study by NASA(2) has indicated that the probability of a collision between spacecraft is not insignificant (on the order of 10^{-3} to 10^{-4}/yr), particularly for polar inclinations which have to cross the path of the majority of orbiting spacecraft. A collison would probably destroy the aeroshell and could, depending on the angle and velocity of impact, cause prompt reentry of fuel fragments.

Future spacecraft containing nuclear heat sources are the Galileo and Solar Polar deep space probes and possible DOD missions which could be either powered with a large radioisotopic heat source or a reactor, and presumably would be in an earth orbit. There are several failure modes of the Space Shuttle and its upper stages that could cause a reentry of deep space probes.

All of the spacecraft listed in Table 1 in low earth orbit (excluding LES 8 and 9) have a total weight of several hundred pounds or less and could be adapted for storage in the Orbiter bay. The more difficult problem, based on conversations with NASA, is how to handle tumbling or spinning spacecraft. For example, the TRIAD 0I-1X could be spinning slowly about a vertical axis. The older spacecraft could be tumbling in a more or less random fashion, presuming that the altitude control mechanisms are no longer operational. The Galileo and Solar Polar spacecraft to be launched would weigh

TABLE 1

Characteristics of Satellites Containing RTGs

S/C	Launch Date	Period min	Inc., deg	Apogee km	Perigee km	Power Source	Inventory of Pu-238 at Launch (curies)	Expected Orbital Lifetime, years	Disposal mode	Pu-238 Fuel Form
Transit 4A	6/29/61	103.7	66.8	993	881	SNAP-3	1,800	570	Burnup	Metallic
Transit 4B	11/15/61	105.7	32.4	1103	953	SNAP-3	1,800	1200	Burnup	Metallic
Transit 5BN1	9/28/63	107.3	89.8	1135	1072	SNAP-9A	17,000	1900	Burnup	Metallic
Transit 5BN2	12/5/63	107.0	89.9	1119	1067	SNAP-9A	17,000	1800	Burnup	Metallic
SNAPSHOT	4/3/65	111.6	90.0	1313	1282	SNAP-10A	reactor	5000	Burnup	
Nimbus III	4/14/69	107.3	99.7	1135	1074	SNAP-19	37,000	3600	Intact Reentry	P_uO_2 microspheres
"Transit" (TRIAD-01-1X)	9/2/72	100.6	90.1	838	742	RTG	24,000	150	Intact Reentry	P_uO_2 molybdenum cermet
LES-8	3/14/76	1440	25.0	35,900	35,900	MHW-RTG	149,600	10^6	Intact Reentry	Pressed and Sintered P_uO_2
LES-9	3/14/76	1440	25.0	35,900	35,900	MHW-RTG	149,600	10^6	Intact Reentry	Pressed and Sintered P_uO_2

several thousand pounds and, once deployed, will be rotating and present an awkward profile for access to the RTGs.

The condition of the fuel and its containment in the various RTGs in orbit is of concern in any recovery operation. RTGs with metallic fuels may have been altered through fuel melting and dissolution of tantalum containment as Peltier cooling degraded. These unvented RTGs may also have considerable internal pressure build-up. The RTG with microspheres as fuel may now contain powder due to microsphere shattering as microsphere internal pressure increased. If venting is fouled, internal capsule pressure may be high. Transit Triad (PMC fuel) may be altered in that the tantalum ten percent tungsten liner is oxidized and embrittled, but it may be in the best condition for orbital recovery operations. It is anticipated that these possibilities will be the subject of another study. In any case, it is likely that orbital decay and reentry would result in an atmospheric release of nearly all fuel material of any of these RTGs.

2.2 Performance

Figures 1 and 2 are the Space Shuttle performance characteristics for a Kennedy Space Center and Vandenberg Air Force Base launch.[3] Currently, these figures are believed to be optimistic based on conversations with NASA personnel. In fact, the payload capability for a polar orbit may be zero. NASA has several concepts for an "Enhanced Shuttle" which would have extra rockets, either solid or liquid, to increase the Space Shuttle performance. This is currently in the NASA budget. It is likely that the official performance estimates (Figures 1 and 2) could be met or exceeded by the time the special requirements for RTG/heat source retrieval are developed.

Even if the performance were as shown in Figures 1 and 2, the Space Shuttle could rendevous with the Transit 4A, 4B and TRIAD 0I-1X spacecraft and would require the addition of 3 Orbital Maneuvering System (OMS) kits to the Orbiter. Additional retrieval capability could be attained by the use of a Teleoperator Retrieval Spacecraft, discussed later.

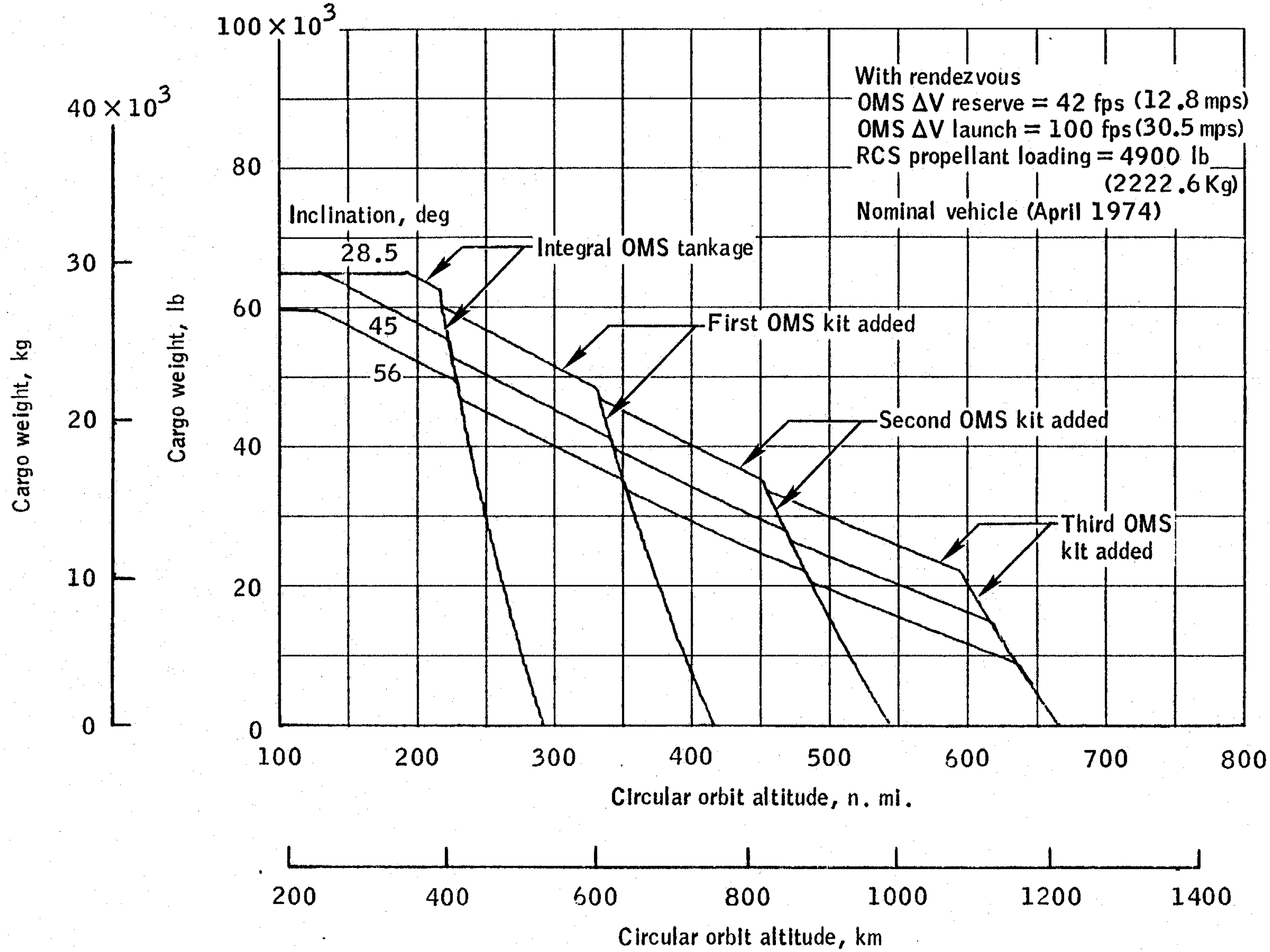


Figure 1
Cargo Weight versus Circular Orbital Altitude - KSC Launch, Delivery and Rendezvous.

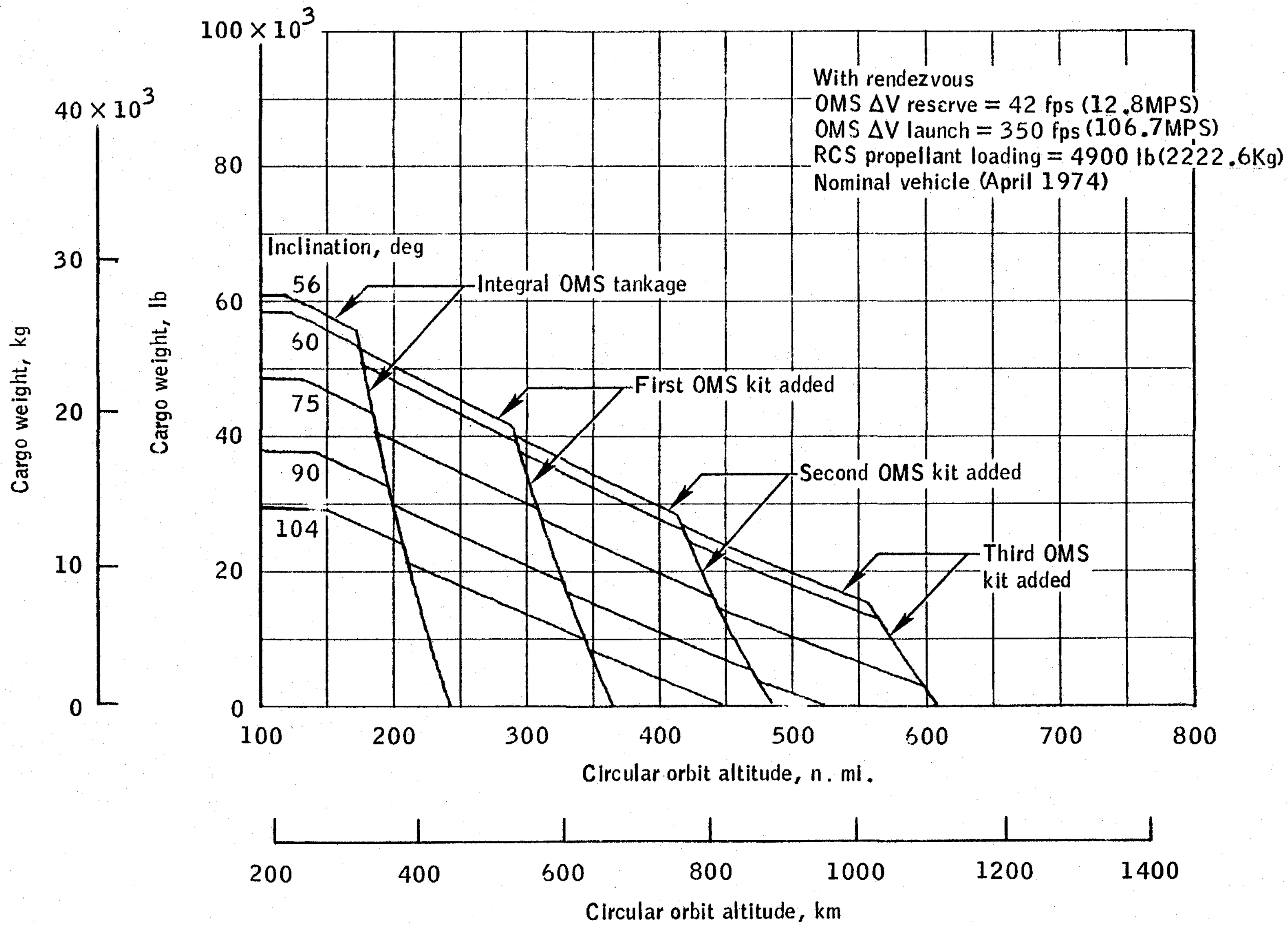


Figure 2
Cargo Weight versus Circular Orbital Altitude - VAFB launch, Delivery and Rendezvous.

2.3 Retrieval Capability

The Orbiter has the following methods to interact with a spacecraft:

1. The currently developed remote manipulator system (RMS), which could have several "end effectors" to acquire "cooperative" satellites. This would most likely be applicable to future satellites designed for retrieval and would have limited use for existing ones. The requirements for a spacecraft to be retrieved by the RMS are given as an appendix.

2. A manned maneuvering unit (MMU) being developed by Martin Marietta Corporation, which is a backpack device for an astronaut to perform various tasks external to the Space Shuttle.

3. A mobile television device (MTV) for surveillance and inspection.

4. An open cherry picker (OCP) to suspend an astronaut from a platform anchored to the Orbiter.

Only the RMS could be considered for retrieval of nuclear heat sources.

Some conceptual work has been done for mechanisms to despin or detumble spacecraft. A spinning adapter to synchronize with a spacecraft such as TRIAD 0I-1X (assuming it is slowly spinning) and then mate, despin, and retrieve was suggested by Martin Marietta Corporation. Kaplan[4] has recommended the use of ice sublimation as a way to detumble spacecraft.

2.4 Teleoperator Retrieval Spacecraft

2.4.1 Background

The Teleoperator Retrieval Spacecraft concept was originated as a result of a study conducted from 1965 through 1969 by Marshall Space Fligth Center to emphasize both direct and remotely controlled teleoperator systems, followed by a NASA agency decision in 1970 to reorient its programs toward further emphasis in the area of teleoperations. The development continued at a relatively slow pace until October

1977, when Marshall Space Flight Center was asked to develop a teleoperator system to accomplish the reboost/deorbit of Skylab, with a launch date no later than February 1980. Marshall Space Flight Center is in the process of redefining a comprehensive set of mission and systems requirements for a Remote Teleoperator System (RTS) responsive to mission model requirements over the time period 1984 through 1991.

2.4.2 Description[5]

The teleoperator system provides a propulsive "mini-tug" capability to augment the basic Shuttle Orbiter capabilities for payload placement and retrieval missions beyond those orbits and inclinations which the basic Space Shuttle system can support, but which are below those capabilities provided by other upper stages to be in the Space Shuttle inventory (such as the IUS). Thus, as a "mini-tug", the teleoperator would fill the performance requirements for near-earth low-energy mission model for payloads being delivered to 28.5, 56, 90 and 104° inclination orbits at typical altitudes up to 600 nautical miles. Beyond "mini-tug" operations, the teleoperator will also be required to support subsatellite operations in and around the vicinity of the Orbiter, and to accomodate the latter addition of appendages needed to provide necessary manipulative/grappling/docking mechanism functions for payload retrieval/servicing missions.

As a basic philosophy, all background studies leading to the present concept of a teleoperator have baselined the following approach to configuring a teleoperator system.

"Core" Vehicle - A basic self-contained system utilizing a number of previously qualified subsystems/components to perform a nominal range of mission support functions (i.e., power, propulsion, attitude control, payload viewing, communications, data handling, etc.).

Propulsion Kits - Thrust augmentation kits to provide the added velocity required to support the special class of missions that require greater propulsion capabilities (i.e., longer-duration operations, higher thrust, greater total impulse).

Other Mission-Peculiar Kits - The basis core vehicle via kitting/modifications shall provide capabilities to accommodate unique mission support appendages, grapplers, manipulator(s), services mechanisms, advanced viewing/video systems, docking/retrieval probe/end effector combinations, etc.

2.4.3 Responsiveness To Mission Model/User Needs[5]

The overall objective of the RTS Project is to develop a RTS Core Vehicle and the related mission support/performance augmentation kits needed to support projected mission model/user needs. A synopsis of time-phased requirements is provided below.

Payload Placement Operations (Kennedy Space Center) to 28.5-56° inclinations; nominal altitudes up to 600 nautical miles, some plane change requirements; starting mid-late 1984.

Payload Placement Operations (Vandenberg Air Force Base) to 90, 98, 104° inclinations, nominal altitude up to 600 nautical miles starting in 1984.

Subsatellite Viewing Operations/Scientific Mission Support as a free-flyer, in the vicinity of Orbiter, starting in 1984. In such applications, a vehicle that generates little or no contamination is required.

Payload Retrieval Operations at both short- and long-range distances from the Orbiter, starting in 1985-86.

2.4.4 Performance

Some preliminary studies indicate that the RTS being considered by Marshall Space Flight Center could be launched from the Space Shuttle at 160 nautical miles and retrieve spacecraft at 600 to 1000 nautical miles and possibly make significant plane changes with the "small core" design and with 4 propulsion tanks added. Figures 3 through 5 show the payload weight that can be retrieved as a function of altitude (using 160 nautical miles as the reference Orbiter altitude) for inclinations of 28.5, 56, and 90°. The ability to make plane changes is shown in Figure 6 as a function of payload weight. All currently orbiting U.S. RTGs are within the reach of the RTS except LES 8 and 9.

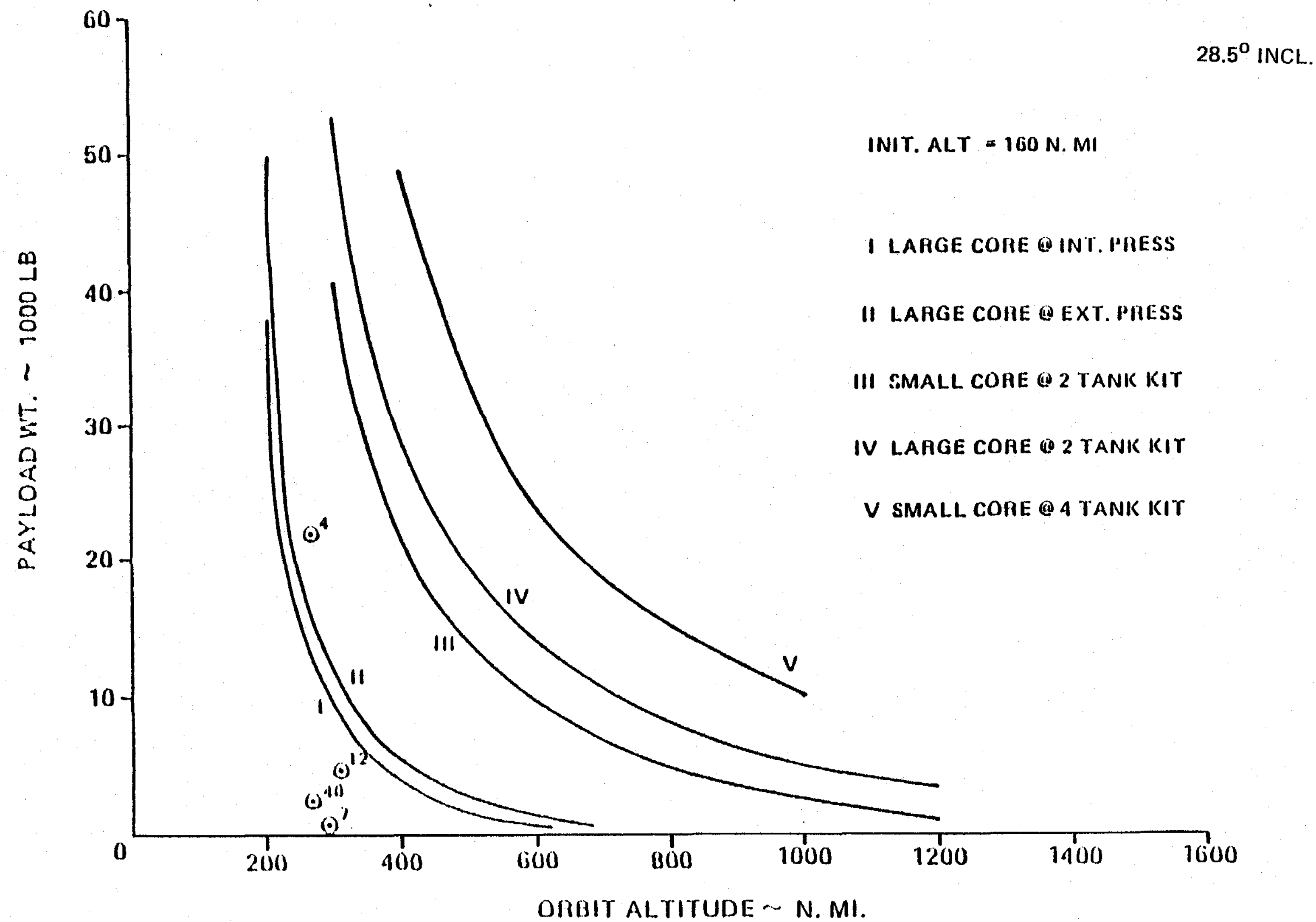


Figure 3
Teleoperator Performance

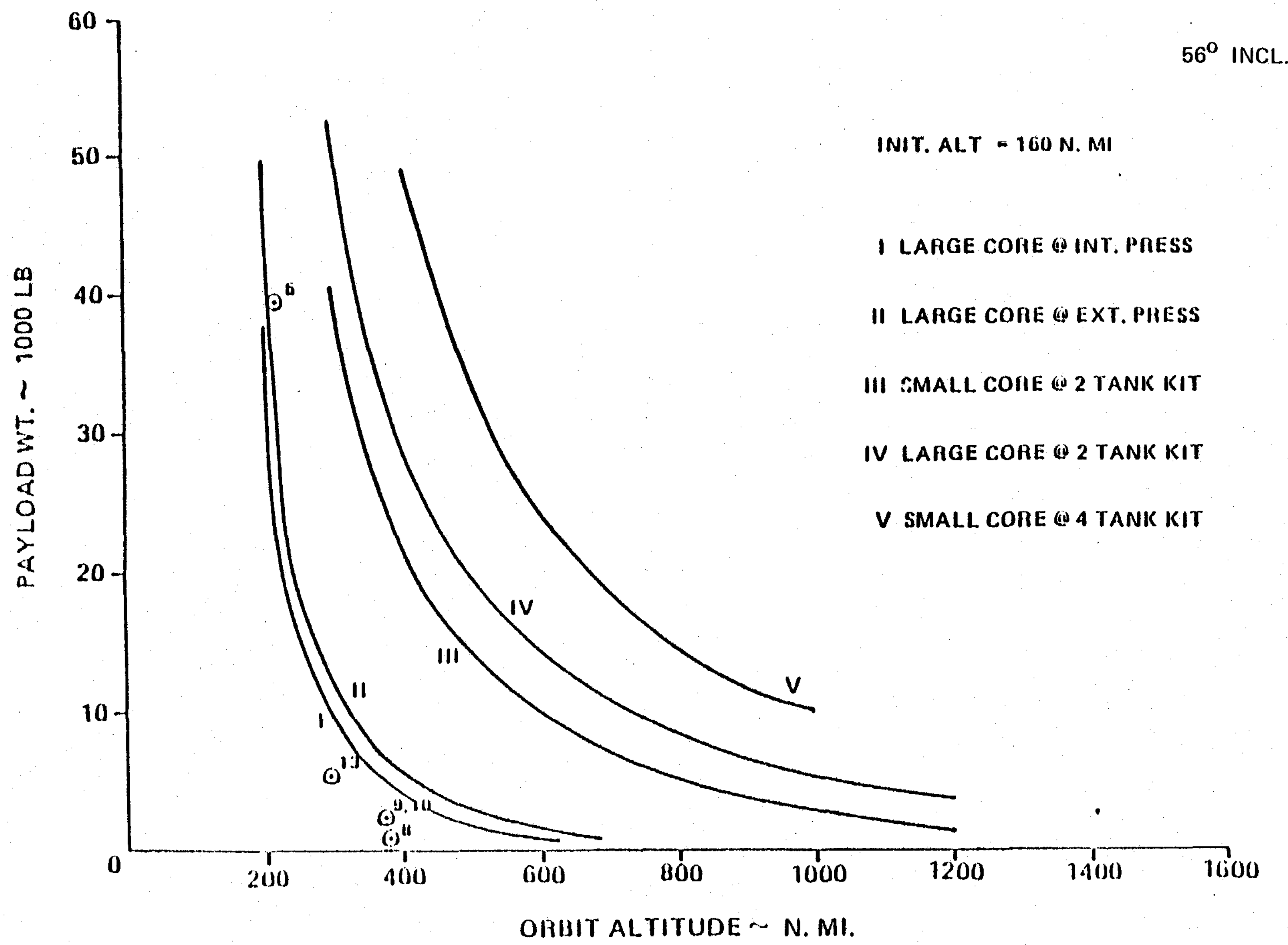


Figure 4
Teleoperator Performance

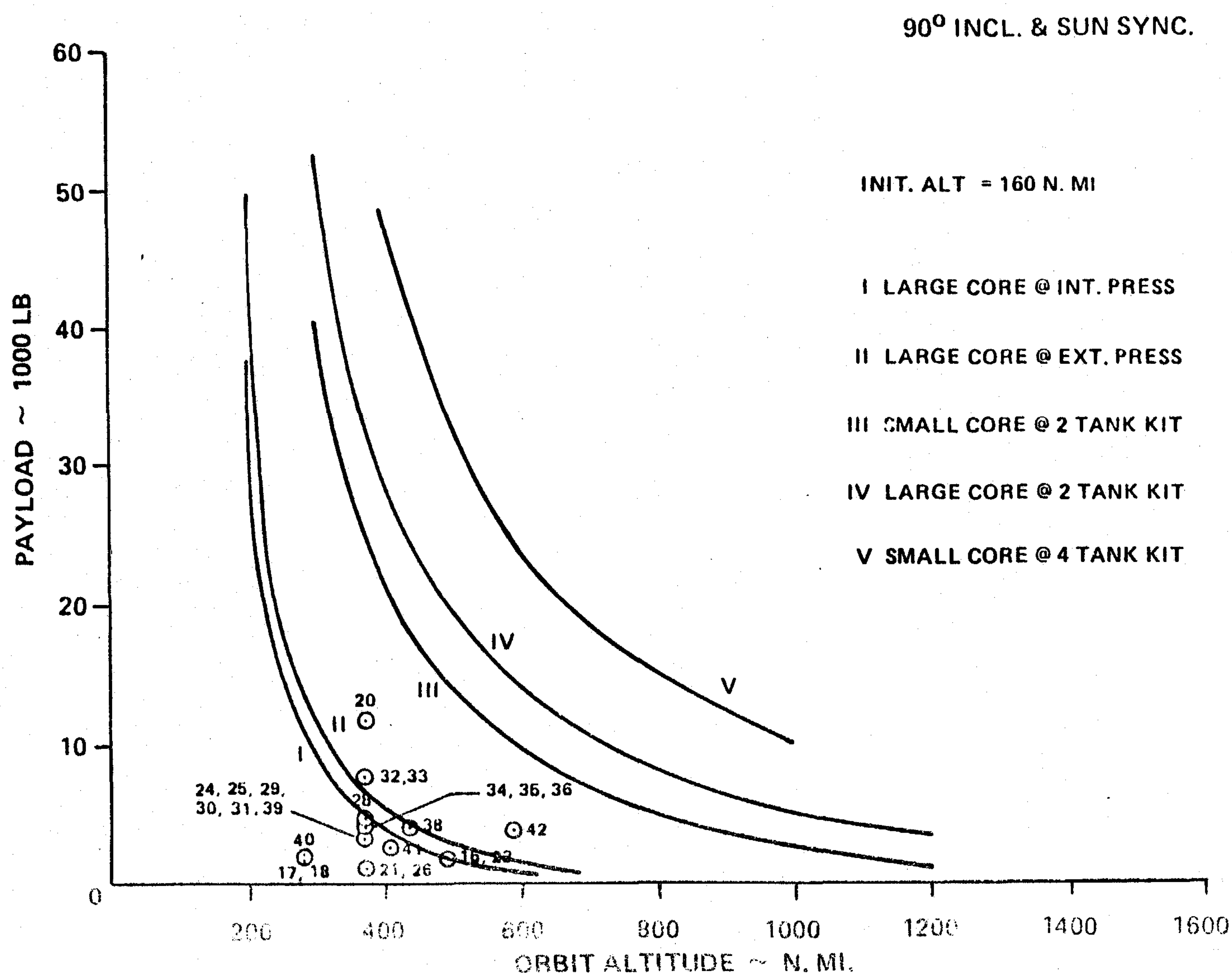


Figure 5
Teleoperator Performance

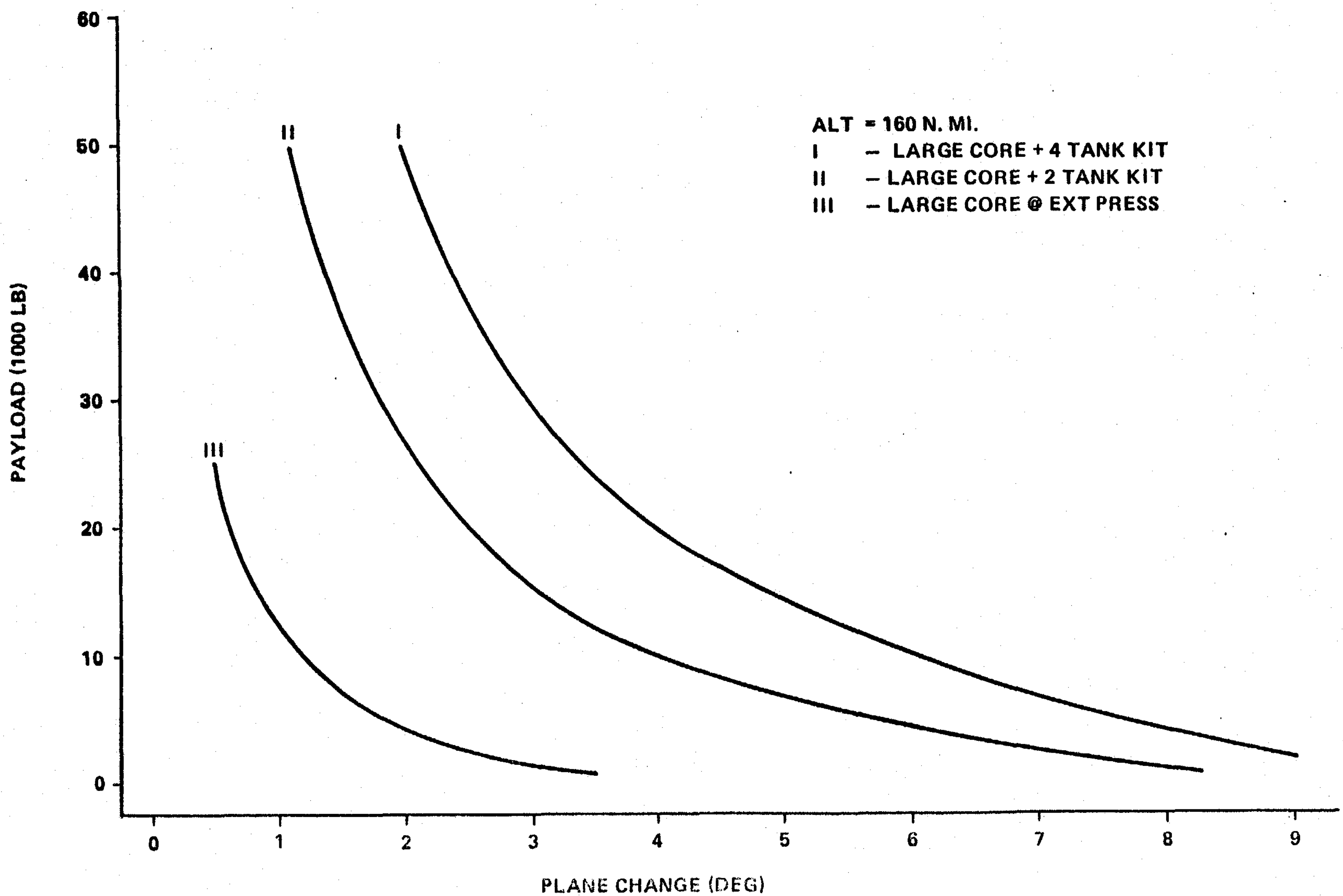


Figure 6
Teleoperator Performance
Plane Change Capability

3.0 CREW RADIATION DOSE CONSIDERATIONS

Payload radiation sources significantly contributing to the radiation levels to which the crew of the Orbiter may be exposed should be shielded and controlled. Table 2 shows the current radiation exposure limits established for flight crewmen and is applicable for RTGs and reactors. It also includes the natural radiation of space. The limits presented in the table have been established by the Radiation Safety Panel for Manned Spaceflight and represent the total allowable radiation limits for the crew from all sources. As a general guide, individual payloads should be designed to a factor of 100 below the limits presented in Table 2, and any requested deviations should be reviewed and evaluated on an individual basis.(6)

In addition to crew injury, the principle equipment-oriented radiation damage considerations are bulk (crystal) damage and ionizing (surface) effects associated with semiconductor electronics, ionization effects in materials, and dynamic interference effects in sensors. The components most sensitive to bulk damage are light-emitting diodes in solid-state displays and high-power semiconductors. Other radiation sensitive devices include grazing incidence X-ray telescopes, air-glow photometers, and nuclear gamma ray spectrometers for high-energy stellar astronomy.

It is understood that new spacecraft containing radioisotopic heat sources would probably be launched by the Space Shuttle and would initially meet the radiological guides of Table 2 for retrieval as well as placement in orbit. Building in of hard decay gammas would increase the radiation field with time. Reactors, once started up and then shut down, would cause high radiation doses to the crew and equipment. Many of the reactors being considered for space applications(7) are largely unshielded and have dose rates of hundreds or thousands of R/hr soon after shutdown when they may have to be retrieved (see Table 3). These could either be boosted to a high earth orbit, boosted to a solar orbit, or deboosted to a controlled location rather than retrieved. Figure 7 shows the initial radiation field for the "Transit" TRIAD 0I-1X. As can be seen, the dose rates are orders of magnitude below those of a reactor.

The space reactors currently envisioned have large radiators attached to the reactor core in order to dissipate the rejected heat. Some means of detaching the radiators from the core could be devised so that only the core, which is relatively small, would have to be shielded. The restrictions on reactors make it unlikely that they could be retrieved by manned systems.

TABLE 2

Radiation Exposure Limits and Exposure Rate Constraints for Unit Reference Risk*

	REM		
	Bone Marrow (5 cm)	Skin (0.01 mm)	Eye (3 mc)
1-year average daily rate	0.2	0.6	0.3
30-day maximum	25	75	37
Quarterly maximum	35	105	52
Yearly maximum	75	225	112
Career	400	1200	600

* For details, see "Radiation Protection Guides and Constraints for Space Missions and Vehicle Design Studies Involving Nuclear Systems, Report of the Radiobiological Advisory Panel of the Committee on Space Medicine, Space Science Board, National Academy of Science, 1970."

TABLE 3

Total Dose Rate From Fission Products and Actinides
For a 1 MW_t Fast Spectrum Space Reactor[8]
R/hr

Distance (m)	Time After Shutdown (yrs)						
	0	1	5	10	50	100	1000
1	2.5×10^6	1.5×10^4	7.5×10^3	6.5×10^3	2.6×10^3	8.0×10^2	0.17
10	2.5×10^4	1.6×10^2	7.5×10^1	6.5×10^1	2.6×10^1	8.0	1.7×10^{-3}

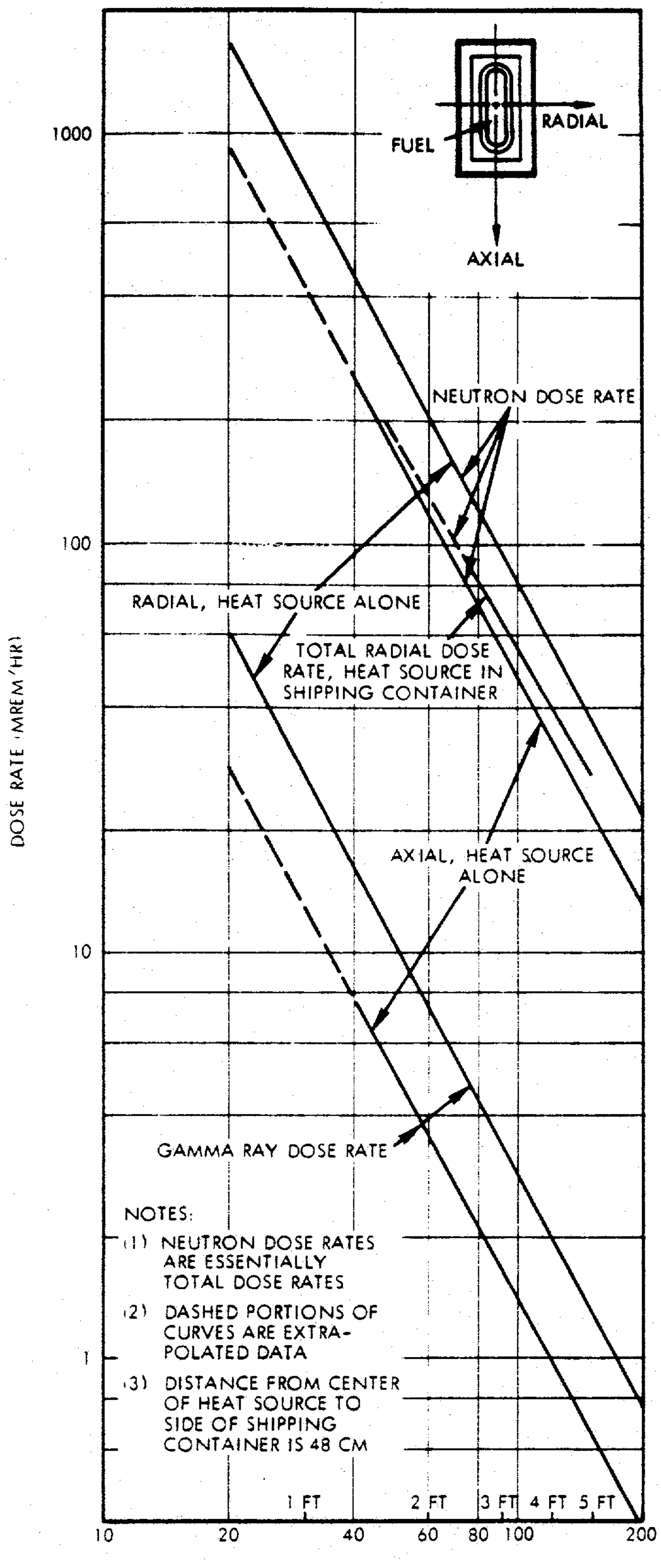


Figure 7
Measured Transit Heat Source Radiation Levels as a Function of Distance from the Heat Source for TRIAD OI-1X

4.0 PAYLOAD INTERFACE REQUIREMENTS AND GROUND HANDLING

4.1 Mechanical Requirements

A detailed description of the payload interface requirements with the Orbiter, as well as the ground handling operations, is given in Volume XIV of the Space Shuttle Level II Program Definition and Requirements. NUS has studied this Volume and updates. The implication of the requirements is that a special cradle or harness for each spacecraft to be retrieved would have to be designed or fabricated for existing spacecraft (i.e., those already in orbit). Each RTG to be a candidate for retrieval needs to be considered separately. It is likely that the RTG would be separated from its spacecraft as a part of retrieval. New spacecraft containing RTG's may be able to use existing cradles, such as those developed for the Multiple Mission Satellite. Enclosed as an appendix is a draft portion of Volume XIV of the Definition and Requirements for Payload Deployment and Retrieval Systems that applies only to the Remote Manipulator System (RMS).

4.2 Special Requirements for RTGs

It will be necessary to perform an evaluation on each candidate RTG for return to determine:

- radiation field
- probable physical state-of-the-fuel material
- probable state of containment
- ability of the heat source to withstand normal and potential accident environments during Space Shuttle return, as well as any despin operations necessary to acquire the spacecraft
- current heat generation rate and heat removal requirements
- current spacecraft stabilization mode (tumbling, spin stabilized, gravity gradient stabilized).

These evaluations will be necessary in order to design the mechanical equipment and procedures necessary for the mission. For example, plans and designs will be needed for satellite acquisition (detumble or despin and capture), RTG separation from spacecraft, shielding and/or containment overpack, if required, and cooling.

Specific plans for ground handling and ultimate fate of the isotopes will also be required.

In addition, it will probably be necessary to perform a safety assessment for the retrieval mission similar to those for launch missions. Potential accidents or incidents which should be addressed would include failure of containment during satellite acquisition, cooling system failure, control failure of the Space Shuttle with uncontrolled reentry and impact, landing crash and fire/explosions, and forced landing at an alternative site. Part of this assessment would be consideration of alternatives such as no mission, boost to higher orbit, or boost beyond earth's environment.

It is likely that a containment overpack designed to provide cooling through external connections will be required. This overpack will provide some shielding.

Upon landing, the RTG with overpack would be removed from the Space Shuttle and placed in a shipping cask suitable for truck transportation of radionuclides in accordance with DOE regulations or NRC's 10CFR71 requirements. This would provide additional shielding, impact and fire protection, and external cooling.

The ultimate fate of the fuel material would likely be determined by economic considerations. The remaining Pu-238/Pu-239 might be extracted economically and reused. Alternatively, the RTG could be treated as high-level (TRU) waste. In that case, current practice would dictate storage until waste solidification and burial facilities are available (such as the Waste Isolation Pilot Plant).

5.0 RETRIEVAL COSTS

The cost of a retrieval mission is difficult to quantify at this stage of development of the Shuttle Transportation System (STS). Conversations with NASA personnel resulted in estimates of $25 million (1979 dollars) while Martin Marietta Corporation personnel feel it will be closer to $70 million. Many of the required items, such as the Orbital Maneuvering System (OMS) kits and the "Enhanced Shuttle" to get the Orbiter high enough to retrieve a nuclear heat source are currently in the planning stage and have no reliable operational cost figures.

Costs to develop a reliable TRS as an alternative to OMS kits are unknown. Martin Marietta Corporation spent $20 million on the Skylab concept, and many of the design features could be used on a TRS/Space Shuttle retrieval concept. However, DOE would still have the mission costs of a Space Shuttle launch.

The costs do not include any estimate for mission planning, hardware design, or safety assessments. As a rough approximation, such costs might be about the same as for the planning, design, and safety assessments of a mission using an off-the-shelf RTG to be applied to a specific spacecraft.

7.0 REFERENCES

1. "Satellite Situation Report," published quarterly by Goddard Space Flight Center.

2. Kessler, D. J. and B. C. Cour-Palais, "Collision Frequency of Artificial Satellites: The Creation of a Debris Belt," Journal of Geophysical Research, Vol. 83, No A6, June 1978.

3. "Space Shuttle System Payload Accomodations," Johnson Space Center, JSC 07700 Volume XIV, Revision F, September 1978.

4. Kaplan, M. H. and D. C. Freesland, "Use of Water Sprays in Space Rescue and Retrieval Operations," presented at the XXVII Congress of the International Astronautical Federation, Anaheim, California, October 1976.

5. "Remote Teleoperatory System (RTS) Program Definition Activites" NASA/Marshall Space Flight Center Teleoperator Task Team, September 1979.

6. "Space Transportation System Payload Safety Guidelines Handbook," Johnson Space Center, JSC 11123, July 1976.

7. D. Buden, "Nuclear Reactors for Space Electric Power," Los Alamos Scientific Laboratory, LA-7290-SR, June 1978.

8. Bartram, B. W and D. W. Pyatt "A Risk Assessment of Space Reactors (Draft)," NUS-3442, September 1979.

PCIN 05909	SPACE SHUTTLE PROGRAM	PAGE 1 OF __
CR NUMBER S05909	LEVEL II CHANGE REQUEST	INITIATED BY: S.L. DAVIS /mp

CHANGE TITLE:

UPDATE TO VOL. XIV, SECTION 8, "PAYLOAD DEPLOYMENT AND RETRIEVAL SYSTEM"

CHANGE PROPOSALS/REQUESTS IDENT. NO.	LEVEL II DOCUMENTS AFFECTED
	JSC 07700, Volume XIV

DESCRIPTION OF CHANGE:

Revise information in Section 8, Volume XIV and provide data to fill in TBD's. New data/requirements include:

(a) Retrieval Requirements for Payloads

(b) Berthing

(c) Sighting Aid Requirements

Revisions include:

(a) Grapple Fixture Clearance Envelope

(b) Grapple Fixture Target

REASON FOR CHANGE:

Provide information and requirements that are needed by the payload projects to ensure compatibility with the Shuttle Payload Deployment and Retrieval System.

JSC Form 261A (Rev Sep 74) NASA-JSC

PCIN 05909

CR NO. S05909

SPACE SHUTTLE PROGRAM
LEVEL II CHANGE REQUEST

SYSTEM ELEMENT(S) AFFECTED:

- ☐ System Integration
- ☐ Orbiter
- ☐ Space Shuttle Main Engines
- ☐ External Tank
- ☐ Solid Rocket Booster
- ☐ KSC Projects
- ☐ System Software
- ☐ Operations
- ☐ Carrier Aircraft
- ☐ Integrated Avionics
- ☐ VAFB
- ☐ ______

CHANGE IMPACT:

- ☐ Safety
- ☐ Performance
- ☐ Reliability
- ☐ Maintainability
- ☐ Producibility
- ☐ Balance & Stability
- ☐ GSE
- ☐ Spares
- ☐ Flight Manifest
- ☐ Facilities
- ☐ Flight Operations
- ☐ Ground Operations
- ☐ Simulators & Trainers
- ☐ Software
- ☐ Payloads
- ☐ Turnaround
- ☐ Other *(Specify)* ______

EFFECTIVITY:

- ☐ SS-1 (OFT-1) FMOF
- ☐ SS-2 (OFT-2)
- ☐ SS-3 (OFT-3)
- ☐ SS-4 (OFT-4)
- ☒ SS-5 (OFT-5)
- ☒ SS-6 (OFT-6)
- ☒ SS-7 & Subs
- ☒ Other *(Specify)*
- ☐ MPT
- ☐ MVGVT
- ☐ QSGVT
- ☐ IAT
- ☐ OPNS

WEIGHT IMPACT	SCHEDULE IMPACT	COST PER FLIGHT IMPACT
None	None	None

DDT & E COST IMPACT:	FY	FY	FY	FY	FY	FY
DDT & E PROD OPS None						

IMPACT DESCRIPTION:

Change to Volume XIV.

IMPACT OF NONINCORPORATION

Requirements for payload retrieval and berthing by PDRS will not be complete.

RECOMMENDATION/REMARKS

Approve and incorporate update Section 8.0 into Volume XIV.

FORWARDING AUTHORIZATION

SIGNATURE (LEVEL II PRCB MEMBER/SYSTEMS CONTRACTOR)	DATE	LEVEL III CCB DATE

JSC Form 2818 (Rev Oct 77) NASA-JSC

The following revisions or additions should be made to section 8.0 of Volume XIV.

Paragraph 8.1.1.2 should be replaced by the new paragraph below:

8.1.1.2 RMS Performance Characteristics. The velocity of the loaded RMS end effector is controlled such that the kinetic energy of the payload will not exceed that of a 32,000 pound payload moving at approximately 0.2 ft/sec. The velocity of the unloaded RMS end effector is limited to 2.0 ft/sec.

At a time not less than 10 minutes after deactivation of the Orbiter RCS, the RMS will be capable of releasing maximum envelope payloads of up to 65,000 lbs. with the following accuracy:

(a) Attitude within 5 degrees of specified orientation relative to the Orbiter structural coordinate system.

(b) Angular rate of the payload relative to the Orbiter less than or equal to 0.015 degrees per second.

(c) Linear motion of less than 0.10 feet per second.

In the automatic mode, the RMS is capable of accurately positioning the end effector (loaded or unloaded) within ± 2.0 inches (50.8mm) and ± 1° relative to the shoulder attach point. In the manual augmented mode the end effector positioning accuracy is primarily a function of operator visibility.

The manipulator arm will transmit, when fully extended and attached to a payload, loads not exceeding the following:

a. A combined 12 lb. shear force and 160 ft. lb. bending moment at the end effector

b. A 230 ft. lb. torque about the end effector axis. An example of the forces and torques that be applied by the end effector for various arm configurations, are shown in Table 8.1.

The manipulator arm is capable of operating (when exposed to direct and/or reflected sunlight) for not less than:

a. 30 minutes when operating in the cargo bay

b. 120 minutes when operating outside the cargo bay

The unloaded arm can operate with no restrictions on V (vernier) RCS, except that the arm must not be in singularity or reach limit zones. There are no restrictions on PRCS firings if the unloaded RMS is not being maneuvered and if the arm is not in a singularity or reach limit zone; the only exception is that no high-thrust level Z-axis thrusting longer than 0.56 seconds is allowed.

The arm can handle a payload of 32,000 lbs. or less and withstand PRCS firings if the loaded arm is not being maneuvered; only single minimum impulse PRCS are allowed, however, with intervals between firings sufficient to allow RMS motion to settle.

For payloads greater than 32,000 lbs., no PRCS firings are allowed. No restrictions are required for VRCS firings (for Orbiter attitude changes or stabilization) other than no VRCS firings are allowed if the loaded arm is in a singularity or reach limit zone.

The table below summarizes the RMS capability to withstand VRCS and PRCS thrusting under various arm loading conditions. In all cases, the arm must not be in singularity or reach limit zones.

	UNLOADED	≤ 32,000 LB. PAYLOAD	> 32,000 LB. PAYLOAD
VRCS	✓	✓	✓
PRCS	✓, if arm is not being maneuvered and no z-thrusing longer than .56 sec.	✓, if single min-impulse firing and arm not being maneuvered	NO

In general - The VRCS can be used to orient the Orbiter/RMS/payload combination under normal circumstances; the Orbiter can stationkeep with the unloaded arm in a "poise to capture" position (which requires the PRCS). The PRCS cannot be used to maneuver the Orbiter/RMS/Payload if the payload exeedes 32,000 lbs. The Orbiter/RMS/payload can be maneuvered with the low thrust modes of the PRCS, if the payload is very light (below 1,000 pounds). Unique Orbiter/RMS/Payload maneuvering requirements must be evaluated according to specific mission characteristics.

The following sentences should be added to paragraph 8.2.5, Visibility and Lighting:

Operator vision will be required to critical areas of payloads being handled. The individual payload project, in conjunction with NASA will assess the compatibility of the payload structure and the need for operator visibility into critical areas during payload handling operations. Similarly, exterior surfaces that glare into the PDRS operator's eyes or into the CCTV cameras should be avoided. Lighting lab tests may be required to verify acceptability of illumination of specular effects. If unique payload interfacing hardware/systems are utilized, the payload may be required to provide test hardware and resources for conducting simulations to insure compatibility with the PDRS.

The following paragraphs for 8.3.1, "Retrieval Requirements for Payloads", and 8.3.2, "Berthing Requirements for Payloads", should replace existing paragraphs 8.3.1, 8.3.2 and 8.3.3 which were TBD:

8.3.1 Retrieval Requirements for Payloads

To be compatible with the Shuttle Payload Deployment and Retrieval System (PDRS) and associated Orbiter Avionics Subsystems used during rendezvous, proximity operations and capture, the payload must comply with the following requirements:

a. Stabilization at Grapple

(1) Attitude error relative to the desired orientation in the inertial or LVLH reference frame is limited to ± 10 degrees in all axes. For payloads having one or more unconstrained axes, a time history of the nominal payload orientation relative to the payload LVLH reference frame, during the planned retrieval sequence, should be made available preflight.

(2) Angular rate relative to the inertial or LVLH reference frame is limited to ± 0.1 degrees per second in all axes.

(3) Translation resulting from payload uncoupled rotation, venting, etc., is limited to 0.1 accumulated feet per second per axis for any 100 second period during capture operations.

b. Attitude Control and Pointing

As a function of payload type and Orbiter approach technique, there will be a preferred orientation of the grapple fixture relative to the payload LVLH reference frame during the orbital daylight phase. To accomplish this:

(1) The capabilities of the payload attitude control system (3-axis LVLH, 2 or 3 axis solar inertial, passively stabilized, etc.) will be utilized to the maximum extent possible.

(2) In the event the payload stabilization scheme is incapable of providing the proper relative orientation for grapple, multiple grapple fixtures may be required.

c. Payload Control System Activation/Deactivation and Safing

To preclude damage resulting from Orbiter/payload dynamic interaction:

(1) For payloads with translation control authority, the capability must exist, when the Orbiter is in the near vicinity of the payload, to quickly enable/inhibit the payload control system upon crew demand, and provide appropriate verification feedback.

(2) For payloads with only attitude control authority, the capability must exist to inhibit the payload control system at the time of capture.

(3) For all payloads, the capability must exist to verify that the payload control system is safed prior to and during berthing operations.

d. Visual Ranging Aids

Approach and stationkeeping visual ranging aids are required within a range of 500 feet. There should nominally be at least 2 cues, sized such that they produce a COAS subtended angle of approximately 2 degrees at 100 feet and 30 feet, respectively.

(1) The payload structure will be utilized if properly sized cues are discernible.

(2) If the payload structure is not sufficient, special payload painted markings will be required. Typical markings are shown in Figure 8-15.

(3) Because of the dependence of these visual cues on payload relative orientation and Orbiter approach direction, the NASA will determine, on an individual payload basis, the suitability of the payload structure and any requirement for supplemental markings.

e. Nighttime Visibility

For nighttime stationkeeping and final approach, the payload orientation (shape) must be clearly discernible to the crew at a range of 1000 feet, while resolution of the ranging cues and grapple fixture location must be clearly visible to the crew at 500 feet. This requirement can be satisfied by:

(1) Use of the Orbiter overhead flood light, assuming payload surface reflectivity characteristics are compatible.

(2) If reflection characteristics are inadequate, running lights must be provided to assist in nighttime visual determination of payload orientation and grapple fixture location. The capability should exist for these lights to be turned on/off at the discretion of the crew.

f. Tracking and Navigation

(1) For long-range tracking prior to the TPI (Terminal Phase Initiation) burn (19 nmi $< R <$ 250 nmi), the payload must be capable of being tracked by the Orbiter for rendezvous navigation and burn targeting. This requirement can be satisfied by:

(a) Providing a payload transponder compatible with the Orbiter cooperative radar mode, or

(b) Providing payload surface reflectivity characteristics sufficient to insure payload visibility to the Orbiter star tracker in reflected sunlight (equivalent brightness of a third magnitude star) for a minimum of 30 minutes per orbit revolution out to a range of 250 nmi. Failure to meet this long-range tracking requirement will result in specialized mission planning with attendant delta costs and/or degraded mission success probability.

(2) For close-in tracking after the TPI burn (R <19 nmi.), the payload must provide an effective radar cross section of 6.3 meter^2 to support the nominal post-TPI navigation schedule. This cross section would allow the Orbiter passive radar mode (skin track) to acquire and track at a range of 19 nmi., thereby supporting the first scheduled TPM (Thermal Phase Midcourse) maneuver. Smaller cross sections would impact the navigation schedule, resulting in larger trajectory dispersions with associated propellant cost and reduced probability of mission success. The absolute minimum effective cross section requirement of 1 meter^2 will allow radar tracking at a range of 10 nmi. in support of one late TPM. (A cooperative transponder on the payload would preclude the radar cross section requirement.)

8.3.2 Berthing Requirements for Payloads

The PDRS (RMS, scuff plates, retention latch, retention latch guides, and CCTV) is designed to accommodate payloads up to 65,000 pounds and 15' in diameter, as long as the payload does not interfere with the forward and aft bulkhead CCTV camera mounts (see figure 3.1.2.1.4, ICD 2-19001 for the physical envelope). Payloads which will require the removal of these bulkhead CCTV cameras can be accommodated with special payload insertion devices which must be negotiated separatel

To be compatible with the Shuttle PDRS used during berthing, the payload must comply with the following requirements:

a. Orbiter Payload Retention System

(1) If the mating interfaces between the payload and the Orbiter retention system are not visually discernible to the RMS operator, berthing markings on the payload will be required as visual aids to the operator. These will be payload dependent.

(2) The grapple fixture location must be compatible with the RMS reach capability for berthing and deployments.

(3) The grapple fixture must be provided the clearances shown in Figure 8-14.

(4) The payload flexibility plus thermal distortion must comply with the capability of the Orbiter payload latches to overcome them when securing the payload in the retention fittings.

b. Payload Unique Retention System

(1) Items 1 thru 3 above apply here also

(2) The retention system must be compatible with the RMS capability of positioning the end effector within ± 2.0 inches and ± 1.0 degrees.

(3) The payload retention system must accommodate the payload flexibility and thermal distortions.

(4) The operator must be able to view the mating interface of the payload and its retention system with sufficient clarity during berthings and deployments either by direct vision or by the CCTV system. If the existing locations of the TV cameras do not meet the above requirements, special placement of the camera will be required.

(5) The berthing system must accommodate the payload/RMS motions without contact with critical Orbiter or payload surfaces.

(6) If the operator is to do the latching manually, he must be provided with adequate ready-to-latch indications. The time to latch will not exceed 30 seconds.

(7) The payload must provide sufficient protection for such things as propellant tanks and lines to assure that there will be no safety hazard in the event the RMS has a "runaway" type malfunction during the grappling operation.

Replace Figure 8-5 with new Figure 8-5, "Grapple Fixture and Target"

Replace Figure 8-14 with new Figure 8-14, "Precapture Misalignment Envelope"

Add new Figure 8-15, "LDEF Targets"

NASA-S-79-2687

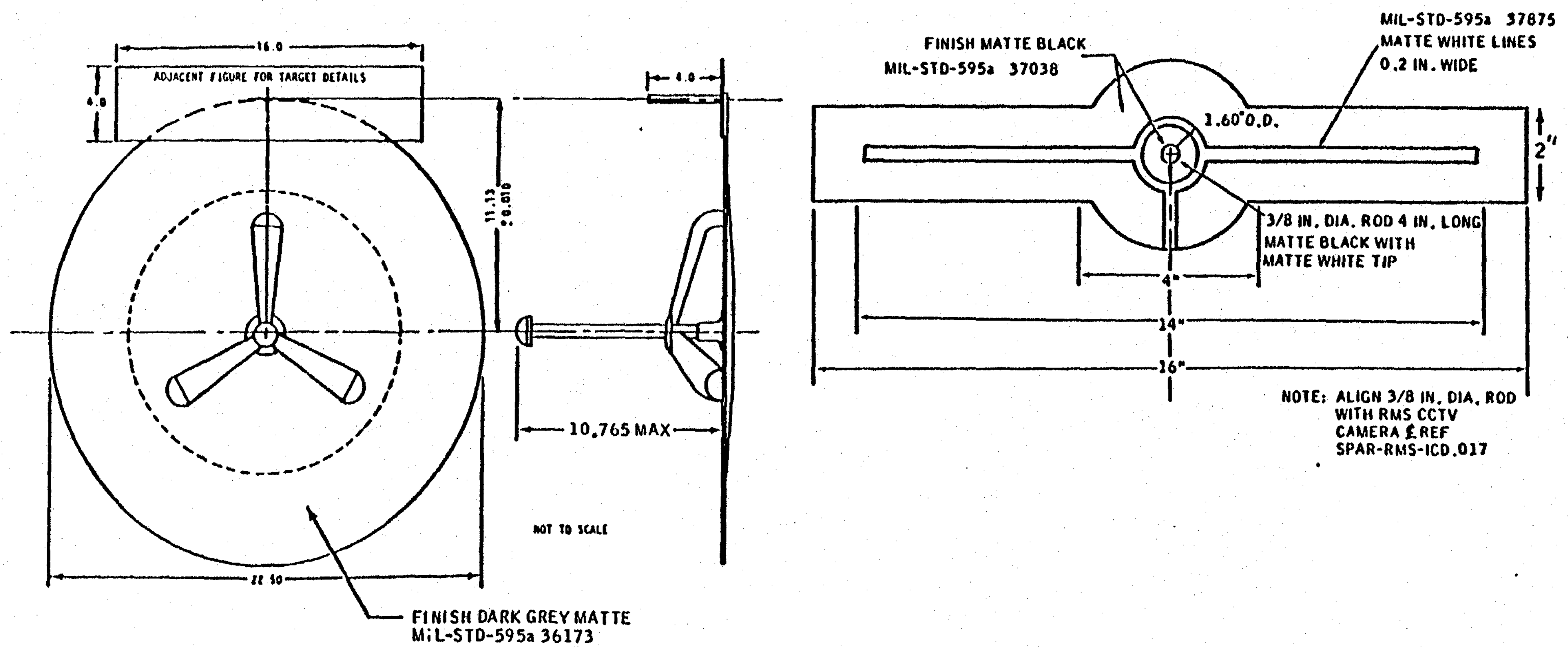
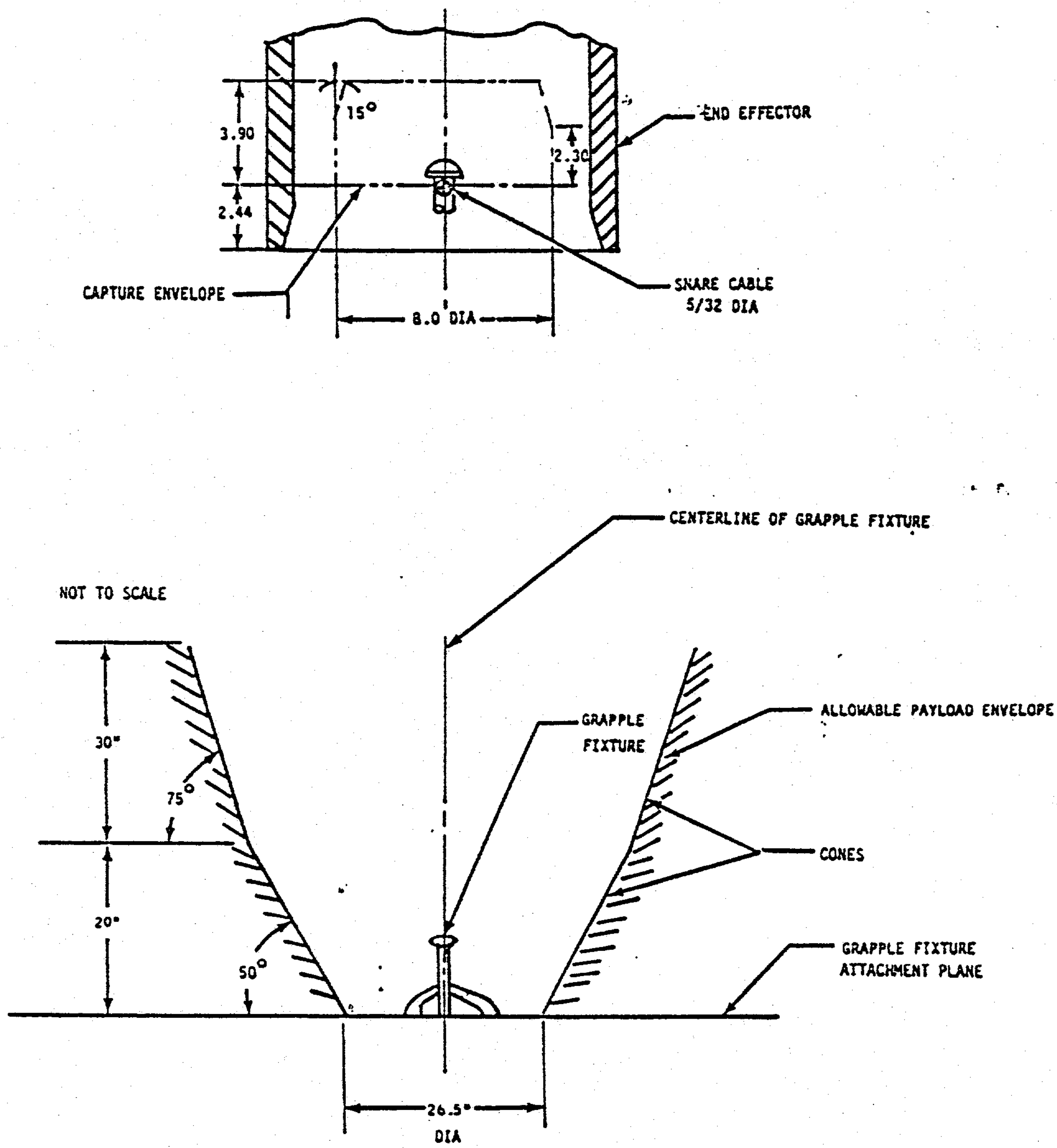


FIGURE 8.5 GRAPPLE FIXTURE AND TARGET

NASA-S-79-1067 B



NOTES:

① CLEARANCE VOLUME CENTERED ON CENTERLINE OF GRAPPLE FIXTURE

② CLEARANCES REQUIRED BEYOND 50 INCHES FROM THE ATTACHMENT PLANE WILL BE DEPENDENT ON THE PAYLOAD AND THE REQUIRED ARM CONFIGURATION

③ THE GRAPPLE FIXTURE/TARGET MOUNTING ORIENTATION ON THE PAYLOAD WILL BE DETERMINED BY THE OPERATIONAL TASK AND THE REQUIRED VIEWING REFERENCE FOR THE OPERATOR.

FIGURE 8-14 PRECAPTURE MISALIGNMENT ENVELOPE

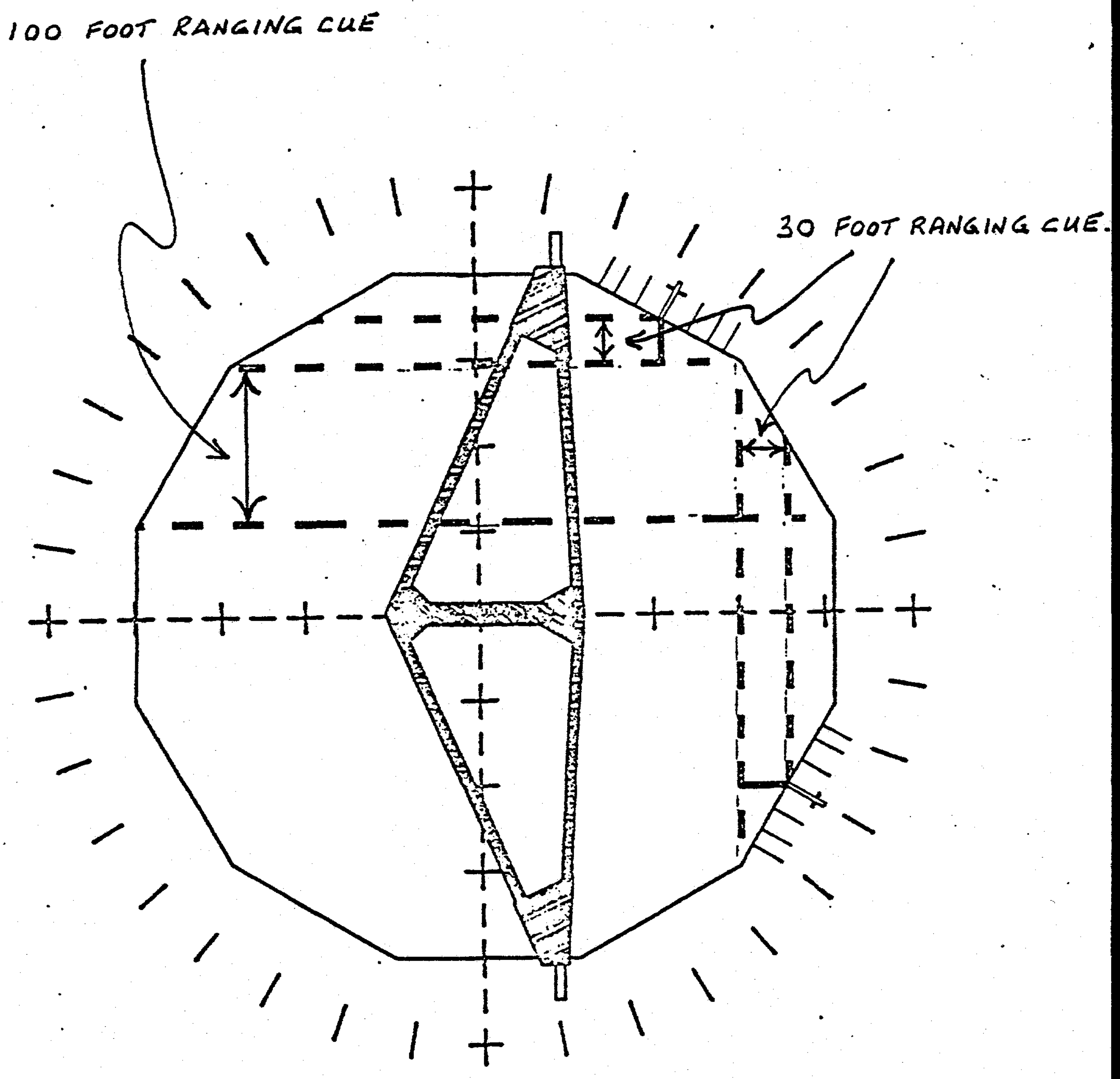


Figure 8-15 - Utilizing the LDEF Targets IN THE COAS RETICLE