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WANL-TNR-155

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ANTICRITICALITY
POISON SYSTEM
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March 30, 1964

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Subject: WANL-TNR-155, Status Report Anticriticality Poison System (ACPS)
March 6, 1964

Dear Mr. Schroeder:

Transmitted herewith is one (1) copy of the subject report.

This report is transmitted for your information.

Respectfully,

H. F. Faught, Program Manager
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cc: Mr. V. R. Miller
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FOREWORD

Under certain accident situations the control system for the NRX reactor cannot be relied on to maintain the reactor subcritical. The control drums do not contain enough poison to prevent a nuclear excursion if, for example, the reactor is immersed in water, or if hydrogenous rocket propellant enters the reactor core with sufficient density. Also, during the period prior to reactor operation the control drums cannot always be positively locked in their least reactive positions. Therefore, some additional device or method must be used to guarantee subcriticality of the reactor prior to the time it is operated.

One method already developed is the insertion of poison "shipping" wires in the reactor coolant channels. These wires, 6800 in number, are stainless steel tubes filled with boron carbide and encased in polyethylene. They are inserted during reactor assembly and removed just prior to attaching the nozzle to the reactor. This method is adequate for the reactors to be used in the NRX test series; however, the shipping wires cannot be withdrawn through the nozzle, and thus cannot be used to "safe" a reactor between the time the nozzle is attached and the reactor is operated.

A second system, currently being studied, is an anticriticality destruct system (ACDS). Essentially, ACDS would explode the reactor upon actuation of a command signal. It is conceivable that ACDS would use part of the post operational destruct system (PODS). PODS is designed to explode the reactor into small fragments after operation of the reactor, the purpose being to prevent large pieces of highly radioactive material from being deposited on the earth's surface.

A third system that has been proposed is an anticriticality poison system (ACPS). ACPS, as presently conceived, is an arrangement of poison wires inserted in the reactor coolant channels and connected to a mechanical withdrawal actuator. The withdrawal actuator is mounted in the nozzle and, on a given signal, pulls the poison wires out of the coolant channels into the nozzle. Wires and actuator separate from the nozzle with the second stage. This system has distinct advantages:

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- 1) The reactor is positively poisoned as long as the wires are inserted.
- 2) As long as the poison wires are inserted, no portion of the reactor core can be formed into a critical mass.
- 3) ACPS will not damage the reactor, the engine, or any other part of the rocket.
- 4) ACPS can maintain the reactor subcritical without interruption from the time the reactor is assembled to the time it is operated in space.

In 1962 WANL began testing the feasibility of ACPS. Simply, the question was whether a large number of poison wires could be withdrawn from reactor coolant channels through a nozzle throat without damaging the coolant channels, the columbium coating on the reactor core face, or the wires themselves. Tests and calculations showed that Teflon coated metal wires could be withdrawn without damaging reactor components, and that a maximum of 4000 of these could be withdrawn readily through the nozzle throat.

Investigation found that boron₁₀ was a suitable poison material. Other poisons such as gases, fluids, beads, and solvents were investigated, but none showed significant promise. The preliminary poison wire design calls for a stainless steel tube filled with boron₁₀ and sheathed in Teflon. With 2382 of these wires distributed uniformly in the reactor core, the reactor immersed in water, and the control drums in their maximum reactivity positions, the k_{eff} is 0.95. The preliminary design recommends adding 238 wires as a safety factor.

The investigation of ACPS also focused on the wire withdrawal actuator. Several schemes were studied. In each the wires connect to a retainer plate in the nozzle throat; on signal a drive mechanism locks onto the retainer plate and pulls the wires into the nozzle.

The investigation of ACPS has been curtailed. Studies of withdrawal actuators have been temporarily cancelled. However, studies of poison wires continue along several paths:

- 1) investigation of poison materials that can replace the very expensive boron₁₀;
- 2) development of a solid metal poison wire, which would not be as expensive to fabricate as a filled tube;

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- 3) investigation of non-metallic tubes to contain the poison;
- 4) further examination of the forces accompanying wire withdrawal, and investigation of methods to reduce the damage potential of these forces;
- 5) further investigation of the effects of wire shape and wire-sheathing material on frictional and other forces, and thus on the pull force needed for withdrawal; and
- 6) further investigation of methods to prevent wire movement prior to withdrawal.

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SECTION I
INTRODUCTION

This report describes the current status of the development of an anticriticality poison wire system (ACPS). Several concepts have been defined and a preliminary analysis made. By describing the accomplishments to date, the report is intended to provide a base on which future development can build.

In Section II the report describes the overall system and the current state of each system part. Section III compares five withdrawal actuator designs and presents a detailed analysis of the most promising design, a winding tape actuator. In appendices the report lays down the guidelines for the ACPS design, presents a tentative specification for the system, and tabulates and analyzes the data obtained thus far from tests of a simulated ACPS.

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SECTION II SYSTEM DESCRIPTION

INTRODUCTION

The anticriticality poison system (ACPS), as presently conceived, is independent and self contained. System power and system control are not derived from components designed primarily for other functions. This independence of the system allows the most efficient use of space and the most efficient use of support structures. Also, components can be selected that best fulfill the system needs; selection is not compromised by other-system requirements.

The anticriticality poison system has seven divisions:

- 1) poison wires,
- 2) poison wire support and retention system,
- 3) retractor lock,
- 4) poison wire withdrawal actuator,
- 5) energizing gas stowage,
- 6) system mounting and support structure, and
- 7) gas transfer valves, control, and electric circuitry.

The following paragraphs describe the current design in each division, and suggest investigations of refinements and alternates.

The poison wire withdrawal actuator here described is the winding tape device, which is the most promising of the five devices currently considered. Section III compares the five actuator designs.

POISON WIRES

The current system design requires that more than 2600 poison wires¹ be inserted in the reactor core to keep the reactor subcritical under the specified hazard and normal conditions of reactor handling, flight preparation, and flight operation.

---

¹WANL-TME-603, Selection of Material, Number & Distribution of Poison Wires for the Anticriticality Poison System.

Figure 1
Anticriticality Poison System (ACPS), Showing Winding Tape Accelerator

The wires are stainless steel tubes packed with boron B₁₀ powder. They are inserted in a pattern approximating a uniform distribution of wires over the gas outlet face of the reactor core.

Teflon sheaths, with a low coefficient of friction, are shrunk onto the stainless steel tubes to reduce the force needed to insert and withdraw the poison wires. Also, by reducing the friction between the wires and the fuel element coolant channels and fuel cluster support blocks, the Teflon sheaths lessen the possibility of scoring or chipping surfaces.

POISON WIRE SUPPORT AND RETENTION SYSTEM

Purpose

During reactor handling, flight preparation, and flight operation, it is essential that the poison wires be held in position. Further insertion of the wires in the coolant channels may damage flow restriction orifices; withdrawal of the wires will increase the reactor k_{eff} . Once the wires are installed in the position in which they maintain the required negative reactivity, the poison wire support and retention system must prevent significant wire displacement. (See figure 1.)

Also, although the wires themselves probably would not be affected, wire movement could damage reactor components. A second function of the wire support and retention system is to prevent such movement.

Gouging

During withdrawal, all poison wires must be pulled through the nozzle throat. Since most wires are inserted at radially greater distances than the nozzle throat radius, the withdrawal force for most wires is not parallel to the longitudinal axis of the withdrawal mechanism. Thus, the end of a typical wire tends to gouge the channel wall as it approaches the outlet of a coolant channel.

The Teflon sheath helps to prevent gouging, and tapering of the wire end will further eliminate this effect. If tests show that additional prevention is needed an extension can be fitted to the core. The extension, probably not more than two inches long, would delay the gouging action until the wire ends reached the extension. The

extension would be removed following wire withdrawal: it could be manufactured of plastic, or other temperature limited material, which would decompose, break up, and flow through the nozzle at relatively low core temperature.

Displacement Forces

The wire span between the core outlet face and the nozzle throat must be supported to counteract launch and boost acceleration forces. These forces act in the direction of wire withdrawal. Without wire support in the convergent region of the nozzle, the acceleration forces would cause displacement of the wires from the inserted position. Displacement would progress until positions of rest were established against the nozzle wall or adjacent wires, or until equilibrium was reached with forces generated by the elastic properties of the wire materials.

Frictional force acting between the wires and the coolant channels cannot be counted on to resist wire displacement. Vibration will interrupt contact, producing unpredictable but reduced frictional force.

The wire length spanning the convergent region of the nozzle must also be supported against fluctuating loads and shock loads. These loads will cause lateral displacement of an unsupported wire length and, since the wire end at the nozzle throat is fixed, lateral displacement will withdraw the wire from the reactor core. On removal of the load the wire will not necessarily return to its original position: friction and acceleration forces may prevent return. Succeeding loads will then progressively displace the wire farther.

Fluctuating loads on an unsupported wire span will cause oscillating wire movement that may fret and wear coolant channel surfaces and hole-outlet edges. The Teflon sheath should reduce this effect; however, the support and retention system must prevent any movement that will cause damage.

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Present System Schemes

Wire Supports

One method of supporting the poison wires is to divide them into groups and to bundle each group with bands to constrain outward wire movement. Plastic spacers can be inserted in a group to keep the wires apart.

Hardenable foam could be expanded in the convergent region of the nozzle, or hollow plastic balls inserted to fill the space. Either would dampen and limit movement, and would transmit support reaction forces between adjacent wires and between wires and the nozzle wall or the reactor core face. The foam or balls would deteriorate, break-up, and pass through the nozzle at low levels of reactor startup temperature and flow.

Anchor Ring and Termination Retainer Plate

As shown in figure 1, the poison wires end in terminal links which fasten to a termination retainer plate. The termination plate fixes the spacing of the links, and transmits forces between the links and an anchor plate. The anchor plate is a reference for wire position, and it must be precisely installed and a means provided for keeping it in place.

Retainer Spring

The "flower petal" retainer spring shown in figure 1 holds the anchor plate in place. Acceleration causes an axial movement in the withdrawal direction to deflect the spring petals. Deflection of the petals produces a restoring force which counteracts the force of acceleration. The initial axial movement withdraws the wires, and probably is not tolerable. Also, it cannot be assumed that the wires will return to their original positions once acceleration ceases and the petals return the anchor plate to the reference position. Wire groups may bend the wires held partially withdrawn by frictional force or by blockages introduced in shifting the wire supports.

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The flower petal spring also is not entirely satisfactory in that it imposes a high initial load at the beginning of withdrawal. The load does not decrease until the petals open in the divergent region of the nozzle. For the present configuration this requires several inches of withdrawal travel, by which time the wire pull load is fully developed. Thus, the two loads add at a time when they are near maximum.

Whatever form the anchor plate "retainer spring" finally takes, it should:

- 1) strictly limit movement of the anchor plate until withdrawal begins; and
- 2) when withdrawal begins, it should disengage from the nozzle and give little resistance to the withdrawal movement.

This device should disengage from the nozzle and take on its least resistive shape a fraction of a second before the retractor lock engages the anchor plate. (See below.)

RETRACTOR LOCK

The retractor lock is an arming device. It connects the withdrawal actuator to the anchor plate. The actuator cannot withdraw the wires until the retractor lock engages.

As represented in figure 1, the retractor lock consists of a number of radially acting bolts. These are driven pneumatically to engage a groove in the anchor ring. Three or more bolts are distributed circumferentially. If only two were employed uneven wire pull loading could cause the anchor ring to pivot, which might foul the wires or their support elements.

Designing the retractor lock bolts as pistons in pneumatic cylinders conforms to sound principles. However, the lock must move relative to the gas source, and the design must ensure that the flexible tube or hose supplying gas does not foul the withdrawal actuator.

The retractor lock bolts should be positively held disengaged prior to withdrawal to prevent inadvertent engagement from random shock pulses during vehicle launch. Spring loading of the bolts may be adequate. To prevent accidental disengagement after withdrawal has commenced the bolts should also be locked in engagement.

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In the interests of overall simplification, effort should be made to combine in a single device the functions of retractor lock engagement and anchor-plate retainer release.

As shown in figure 1, the retractor lock is mounted on a guide cylinder. The cylinder prevents cocking of the anchor ring and termination retainer plate. A number of configurations may be substituted for the guide cylinder. Any device which provides loosely fitting sliding contact over an adequate constraining length within the thrust tube will suffice to pilot the wire termination group.

POISON WIRE WITHDRAWAL ACTUATOR

A tape is proposed as the force transmission element between the energy source and the load of the system. A flat tape can wind over itself on a narrow sheave. Use of a cable would introduce guiding problems and would require a relatively large drum. The tape and sheave give a lower weight penalty.

"Elgiloy" appears promising as material from which to manufacture the tape. This is a cobalt-nickel alloy produced by the Elgin National Watch Company. The material may be obtained in a highly ductile strip with a yield strength greater than 200,000 psi.

A pneumatic motor is feasible as the sheave driver. This motor is the usual sliding vane, positive displacement, rotary motor that is small in size relative to output capability. Motor produced torque decreases nearly linearly with speed; maximum torque occurs at stall.

The Chicago-Pneumatic Company has developed a 5 hp air motor for use on an Atlas ICBM. The motor weighs only 9-1/2 pounds without speed-reducing gear train. The motor output can be increased approximately 40 percent for a short operating life by increasing the supply gas pressure 65 to 70 percent. It may be possible to decrease the weight of the motor one to two pounds by changing the rotor material.

Speed reduction gearing will require more attention than the motor itself. Speed reduction of the order of 150 to 1 is needed. Efficient gear trains or planetary gearing appear more promising than a worm gear and worm from the standpoint of overall weight.

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High gear tooth loadings, acceptable for short operating life, generally exclude aluminum or nylon gears. However, if the gears must be large it may be worthwhile to shrink a steel ring onto an aluminum core. Sufficiently strong teeth can be cut in the ring and the gear weight would be reduced.

Since the motor and its gear train will be completely enclosed, they will be protected from the environment. This is desirable because of the wide variations in ambient pressure and temperature possible during flight.

ENERGIZING GAS STORAGE

The gas for driving the motor will be an inert gas stored in aircraft type accumulators. This arrangement presents no hazard. Helium will be considered for the gas. Aircraft accumulators are capable of withstanding several thousand psi. Only several cubic feet of gas at 2000 psi are needed.

SYSTEM MOUNTING AND SUPPORT STRUCTURE

The thrust tube shown in figure 1 transmits the pull reaction to the system structural support members, and maintains the pneumatic motor in the proper location. The thrust tube also stores the poison wires following withdrawal. To provide for reactor operation at low power and flow prior to removal of the ACPS components from the nozzle, holes in the thrust tube wall would decrease flow resistance. If significant weight reduction would result, the thrust tube could be constructed of very thin sheet. Circumferential rings, longitudinal ribs, or combination of rings and ribs would stiffen the tube against buckling during wire withdrawal. A structure built of longitudinal bars braced with rings or cross members may have advantages over a tube structure.

To achieve minimum-weight resisting elements, wire pull reaction forces should be conveyed to the nozzle outlet by support members generally parallel to the wall of the divergent section of the nozzle. The inner extremities of these support members would connect to the thrust tube near the nozzle throat.

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Tensile forces, primarily, would be used to resist withdrawal reaction forces. In comparison to bending-buckling forces tensile forces place the least burden on the cross section of a support member. Consequently, tension resisting support members can be lighter than bending-buckling resisting support members.

However, the system of structural members within the divergent section of the nozzle must accommodate load reversal. Acceleration forces produced during vehicle launch tend to thrust out of the nozzle those components downstream of the throat. This thrust is opposite to the thrust acting on the same components during wire withdrawal. Consequently, buckling components of acceleration forces will be applied to support members aligned parallel to the nozzle wall. To withstand the acceleration forces and the withdrawal forces the support members may have to be aligned differently, if minimum-weight members are to be used.

During stage separation the possibility of contact between system support members and the nozzle wall will be limited. Until an accurate description of the separation operation is available, it will be assumed that the second stage will pivot relative to the third stage about a point in the transverse plane of separation. This point will be taken to be the point of final contact between stages. Based on a Lockheed report² this point is 465 inches forward of the second stage on a vehicle diameter of 396 inches. As a nominal accommodation of stage separation motion, an allowance for one half of a degree of angular misalignment of the geometric axes of the second and third stages is included in system design criteria. As an example of the effect of this allowance, the clearance required between the wall and the nearest support member at the nozzle outlet is slightly more than four inches.

Support members in the divergent section of the nozzle could end at the nozzle outlet in a load distributing ring. This ring can bear on the outlet end of the nozzle, transmitting the withdrawal reaction force in an axial direction into the nozzle. This is acceptable since the gas flow reaction load is in the same direction along the divergent length of the nozzle.

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²LMSC - A301107 NSP-62-7, RIFT S-N Stage Configuration and Structural Conceptual Design and a Supplement.

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Figure 2
 ACPS Electrical and Mechanical Control Element Scheme

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One of the simplest means of retaining system components in the nozzle is to fasten them with cables or rods. A cable or rod can connect at one end to load distributing members at the nozzle outlet, and connect at the other end near the second and third stage separation plate. The cables or rods would be nearly parallel to the longitudinal axis and would not be deflected by acceleration forces. This method would probably cost least in weight.

In place of cables or rods in tension, arches or beams spanning the second stage fuel tank might be employed. To obtain satisfactory rigidity and reasonably low weight, it is likely the network of support members would be extremely complex.

Mounting the system directly on the second stage tank will be investigated. However, this tank is designed to withstand internal loads, not withdrawal or acceleration loads that are imposed on one small area. Even if the tank withstood the loads the resulting deflection might introduce difficult problems. Expansion and contraction of the large second stage tank could affect alignment of the system with the nozzle.

System components not requiring precise alignment can be mounted on the second stage tank; e. g., the gas storage accumulator or the control elements. Flexibility of hose, tubing, or wiring would compensate for motion relative to components precisely located in the nozzle.

GAS TRANSFER VALVES, CONTROLS, AND ATTENDANT ELECTRICAL CIRCUITRY

The poison wires must withdraw within a specific time after receiving the command signal. Figure 2 shows an electrical-and-mechanical control element scheme. A battery powers the amplifier and speed reference circuit. A dc tachometer closes the velocity servo loop from the motor shaft to the summing junction. The system gives the required gain with sufficient stability margin to ensure removal of the wires in the desired time interval.

Over the greater part of the withdrawal distance the motor drives the main speed reducing gear train. A second gear train and switch are tentatively included as a reduced speed reference for approximately the last 10 inches of wire travel. Reduced-speed withdrawal is another means of alleviating wire-end gouging.

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SECTION III

WITHDRAWAL ACTUATOR DESIGNS

INTRODUCTION

After functional considerations, the primary requirement on a withdrawal actuator design is reliability. After reliability light weight is most important.

Five different actuator designs were conceived:

- 1) winding tape actuator,
- 2) multiple pneumatic cylinder actuator,
- 3) lead screw actuator,
- 4) bellows actuator, and
- 5) winding cable actuator.

The five designs were evaluated, and the results are tabulated at the back of this section. The winding tape design was evaluated a month after the other four designs, which were considered concurrently. Consequently, evaluation of the winding tape design benefitted from concepts derived from evaluations of the other four. Also, because of the considerably greater promise of the winding tape design, it was scrutinized more closely.

WINDING TAPE ACTUATOR

The winding tape actuator, shown in figure 1, is the most reliable, lightest, and most compact of the five actuator designs presently considered. The tape transmits tensional force to the wire assembly and, as the wires withdraw, the tape winds upon itself on a sheave. The components, tape, pneumatic motor, and gear train, are proven in practice. The small size of the actuator drive lends itself to complete enclosure, thus protecting precision parts from the environment.

Some areas of the winding tape actuator design merit further attention. The design should ensure that guide cylinder elements will prevent cocking of the anchor ring and the termination plate. Vibration of the tape brought on during launch and flight should not interfere with operation of the actuator.

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Figure 3
Multiple Pneumatic Cylinder Actuator

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MULTIPLE PNEUMATIC CYLINDER ACTUATOR

As shown in figure 3, the multiple pneumatic cylinder design requires a number of components acting in series: the actuator must telescope three cylinders if it is to fit in the space allowed with the wires withdrawn. Piston rings are relied on to hold concentric the relatively large number of moving parts. Consequently, the fully extended actuator is not rigid, and misalignment may interfere with retractor lock engagement. Furthermore, flight induced vibration may cause damaging amplitudes of lateral motion.

The large number of piston rings increases the possibility of leakage. For the rings to seal properly, surfaces must be machined to a low tolerance. Prior to flight the actuator would have to be carefully examined for piston ring cuts, surface dents, and other leak producing flaws.

LEAD SCREW ACTUATOR

As presently conceived, the lead screw actuator (figure 4) is heavier than the winding tape actuator. However, if further analysis finds that a smaller screw and gearing can be used, the lead screw actuator may compare favorably with the winding tape actuator, especially if attitude guidance members are included in the comparison. In the lead screw actuator the screw itself is the chief guidance member.

A disadvantage of the lead screw actuator is the possibility of wire fouling. The nozzle-throat end of the screw is longitudinally fixed. During withdrawal the wires move past the screw as it turns. Fouling of a wire in the screw could jam the actuator, break the wire, or cause the wire to damage reactor core elements. A telescoping shield is being considered as a preventive.

The lead screw actuator, as presently conceived, exposes precision parts to possible damage by handling and to attack by the environment. If the design is used, materials will have to be carefully selected and the precision parts protected.

Figure 4
Lead Screw Actuator

BELLOWS ACTUATOR

A bellows actuator has the distinct advantages of low weight, few parts, and support members that can accommodate both acceleration and withdrawal reaction forces. However, development problems are considerable.

Stress on bellows convolutions is difficult to analyze, and thickness requirements difficult to determine. The diameter, pressurization, and expansion requirements on the bellows shown in figure 5 are at the limit of known bellows capabilities. In addition, this bellows requires that the reactor core be pressurized to approximately 50 psi, or that a second bellows be installed and the space between the two bellows pressurized to a much higher value.

For the bellows to operate properly the seal at the nozzle throat must be tight, and a tight seal is difficult to obtain because the nozzle wall tends to be rough. Also, the nozzle-wall coolant tubes lying side by side form longitudinal corrugations. The corrugations will vary from nozzle to nozzle, which eliminates manufacturing a seal to specific dimensions before the tubes are installed. One sealing technique being considered is the injection of adhesive into a performed peripheral cavity, one wall of which is the nozzle throat.

WINDING CABLE ACTUATOR

The winding cable actuator design (figure 6) is based on the same principles as the winding tape actuator, and it enjoys some of the same advantages. However the cable cannot wind upon itself, and a guide mechanism must be added to the system, which reduces overall system reliability. In addition, the cable drum is much bulkier than the tape sheave, adding weight to the system. Because of the drum size and the consequent span to be supported, the motor probably cannot drive the drum directly, which means introducing additional shaft bearings and shaft alignment requirements.

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Figure 5
Bellows Actuator

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Figure 6
Winding Cable Actuator

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CONCLUSIONS

Although each withdrawal actuator has features that warrant further scrutiny, a comparison of tables 1 through 5 shows that the winding tape actuator best fulfills each design requirement. Of all the designs the winding tape actuator uses components proven most reliable in actual operation, and the least development work is needed on this actuator. (Table 6 lists information on the individual parts of the actuator.) Finally, the large margin with which this actuator meets reliability and weight requirements allows for unforeseen difficulties.

It is recommended that any further design effort on the withdrawal actuator be primarily concentrated on the winding tape design.

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TABLE 1 WINDING TAPE ACTUATOR EVALUATION

Item	Weight (lbs)	Mat'l	Analysis Validity	Design and System Complexity	Development Effort	Safeguards Compatibility	Remarks
Complete system	160.9	-	-	Proven principles and devices; spool-tape scheme is light and simple	System simplicity ensures minimum development effort	Minimum influence	Most promising for high reliability of components
Wire support retainer	2.74	SS	Fair	Leaf spring type; acceptable nozzle wall load distribution	Simulated load testing	Mandatory for wire retention; launch acceleration forces may cause premature movement	Axial travel to develop acceleration resistance probably too great
Retractor lock	2.2	Al & Mg	Good	Attain mechanism simplicity; ensure positive engagement and locking	Testing of positive engagement and positive locking; study stability during extraction	Must not engage under accident conditions or prematurely	-
Guide cylinder	3.5	Mg	Good	Prevention of binding and cocking with thrust tube	Simple slide elements of suitable material	-	-
Guide cylinder release mechanism	0.4	SS	Good	Obtain proper trip under severest conditions	Assurance testing	-	-
Thrust tube	29.2	Mg	Good	Minimize weight	-	-	Tube houses extracted wires
Structural support network	25.2	Mg	Complex	Accommodate load reversal; minimize weight	Method of attachment to main structure; structural tests	-	-

TABLE 1 - Continued

Item	Weight (lbs)	Mat'l	Analysis Validity	Design and System Complexity	Development Effort	Safeguards Compatibility	Remarks
Motor, tape, accessories	31.0	Steel & Al	Good	Material and loading trade off to minimize weight	Environmental testing	-	Light weight prototype already developed for space applications
Accumulator	25 dry 30 loaded	Al	Good	Standard item	-	Helium presents no fire hazard	-
Control system	12	Al	Good	Standard items and accepted combination	Verification checkout	-	-

RELIABILITY EVALUATION

EFFECTS OF SEPARATION	UNIFORMITY OF OPERATION	CONSTRUCTION	COMPLEXITY
1. Likely to be best arrangement especially if guide cylinder can be telescoped or eliminated.	1. Likely to prove the best arrangement of pulling force and velocity. 2. Requires some induced friction to reduce effects of transients.	1. Probably simplest to build in terms of precision. 2. Should be capable of replication with wide tolerances on details. 3. Offers good medium for large safety factors without large increase in size. 4. Amenable to use with redundant power source and drive.	1. Simplest configuration analyzed. 2. Cylinder release mechanism will require special care. 3. Wire support retainer should be splined or otherwise prevented from twisting.

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TABLE 1 - Continued

FAILURE MODES	INTERACTIONS	TEMPERATURE EFFECTS	PRESSURE EFFECTS
1. Tape failure: not likely: good margins available.	1. Motor drive-to-skirt support.	1. Low temp operation of tape reel presents problem in lubrication. Pneumatic motor should be satisfactory. Electric motor should be no problem.	1. No significant effect.
2. Binding guide: motor stall.	2. Piping and accumulator must be accommodated.	2. Effects on lubrication of guide sleeve must be considered.	
3. Binding latch pin on guide release: design problem.	3. Reverse forces unlikely.	3. Tolerances on retractor and pulling head may be affected.	
4. Locking of guide to pull head due to misalignment: design problem.	4. Electric motor drive as an alternate requires power.		
5. Tape winding failure due to slack tape and tape misalignment: must produce pre-tension.	5. Guide cylinder release and retractor lock electrical controls, as well as telemetry require connections, cabling, etc.		
6. Sheared latch pin due to vibration causing guidehead misalignment: pre-tensioning helps but could be a design problem.			
VIBRATION EFFECTS	ADJUSTMENTS	OTHER INERTIAL FORCES	HAZARDS
1. Tape vibration could induce effects on latch pin, leading to misalignment in the extractor head.	1. Requires alignment fixture.	1. Not significant	1. Appears as best arrangement for accident conditions, including handling, fire, explosion and wreck.
2. Same condition could lead to fatigue failure at tape connection to extractor head.	2. May require pre-tension.		
3. Tape loosening must be prevented to ensure tape remains within sheave.	3. Pulling head (retractor) requires detenting.		

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TABLE 2 MULTIPLE PNEUMATIC CYLINDER ACTUATOR EVALUATION

Item	Weight (lbs)	Mat'l	Analysis Validity	Design and System Complexity	Development Effort	Safeguards Compatibility	Remarks
Complete system	296	-	-	Space limitations produce actuator complexity	Extensive lateral and column stability analysis and testing required; checking on reduction of leakage potential	Uncertainty in engagement of retractor locks	May require lateral motion constraint features
Wire support retainer	10	Steel	Fair	Leaf spring type appropriate to withstand acceleration loading; acceptable nozzle wall load distribution	Observe action under simulated load testing	Mandatory for wire retention; launch acceleration forces may cause premature movement	-
Retractor lock	15	Steel	Good	Mechanism simplicity; positive engagement and locking	Actuation, engagement and locking assurance testing	-	Allow for S-II tank expansion
Pneumatic actuator	155	Steel	Good	Critical and highly toleranced surfaces tending to articulation and flexing; maintain arm position under acceleration, multiple potential leakage paths; piston motion sequencing and timing	Extensive assurance testing with emphasis on dynamic loading	Assurance of arming required	Critical component sensitive to loading and susceptible to damage
Baseplate	9	Al	Good	Allow for S-II tank expansion	-	-	-

TABLE 2 - Continued

Item	Weight (lbs)	Mat'l	Analysis Validity	Design and System Complexity	Development Effort	Safeguards Compatibility	Remarks
Structural support network	55	Al	Complex	Reducing weight; stage attachment; reversal of load direction	Attain high structural efficiency	-	REON interface and coordination
Accumulator	15 dry 17 loaded	Al	Good	Standard	-	Helium presents no fire hazard	-
Control valves, regulator and tubing	35	Al & rubber hose	Good	Standard items and combinations; proper sequence and timing of operation; guide hose to avoid fouling	Minimal	-	-

RELIABILITY EVALUATION

EFFECTS OF SEPARATION	UNIFORMITY OF OPERATION	CONSTRUCTION	COMPLEXITY
1. Not likely to bind when fully retracted. 2. Requires disconnect. 3. May need large separation force since design may not permit complete retraction through nozzle throat.	1. Similar to bellows, perhaps more chance to bind. 2. Velocity control could be a problem.	1. Variability in rings and seals will require a large over-pressure capability which is deleterious without additional controls. 2. Requires precision in ring, seal, and cylinder design.	1. Requires a large number of seals that must be operable at low temp. 2. Flexible pressure base required; must be kept free of wire bundles. 3. May need pressure control.

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TABLE 2 - Continued

FAILURE MODES	INTERACTIONS	TEMPERATURE EFFECTS	PRESSURE EFFECTS
1. Bad seals. 2. Open pressure line; clogged line. 3. Cocked piston, binding piston. 4. Frozen retainer spring. 5. Frozen piston. 6. Compressed piston prior to need.	1. Base attached to skirt/support. 2. Requires gas supply.	1. Sensitive to moisture in feed lines & pistons; possible freezing. 2. Should be able to make natural adjustment to axial contraction	1. Requires bleedoff at each stage or holding mechanism since pressure system is closed except at large cylinder.
VIBRATION EFFECTS	ADJUSTMENTS	OTHER INERTIAL FORCES	HAZARDS
1. Essentially a floating mass susceptible to lead effects from vibration. 2. Could vibrate out of alignment.	1. Will require an alignment fixture, but more accessible than bellows.	1. Requires restraintment during launch, as above.	1. Handling: not as critical as bellows. 2. Fire. 3. Explosion. 4. Wreck. 5. Gas leak.

TABLE 3 LEAD SCREW ACTUATOR EVALUATION

Item	Weight (lbs)	Mat'l	Analysis Validity	Design and System Complexity	Development Effort	Safeguards Compatibility	Remarks
Complete system	322	-	-	Screw restricts throat area for wire removal, requires protection of screw and bushing tolerances	Requires method of protecting wires from screw	Wire damage and fouling potential by screw	Rugged but high in weight
Wire support retainer	10	Steel	Fair	Leaf spring type; appropriate to withstand acceleration loading; acceptable nozzle wall load distribution	Observe action under simulated load testing	Mandatory for wire retention	-
Retractor lock	15	Steel	Good	Mechanism simplicity, positive engagement and locking; screw protrusion limits space	Actuation, engagement, and locking assurance testing	-	Allow for S-II tank expansion
Saginaw nut	5	Steel	Good	Stock item	-	-	-
Screw	24	Al	Good	Standard design; high speed requirement; material and lubrication selection	Assurance testing	Wire damage and fouling potential	Consider light plastic sheath for screw
Guide tube	70	Al	Good	Counteract nut torque; minimum weight	-	-	-
Baseplate	9	Al	Good	Allow for S-II tank expansion	-	-	-

TABLE 3 - Continued

Item	Weight (lbs)	Mat'l	Analysis Validity	Design and System Complexity	Development Effort	Safeguards Compatibility	Remarks
Structural support network	55	Al	Complex	Minimizing weight; stage attachment; reversal of load direction	-	-	-
Pneumatic motor	30	Al & Steel	Good	Material selection to minimize weight; bearing and lubrication requirements	Environmental testing	-	-
Accumulator	40 dry 80 loaded	Al	Good	Standard item	-	Helium presents no fire hazard	Optimize location
Control valves regulator and tubing	12	Al	Good	Standard items and combination	Minimal	-	-
Drive plate, gears, and bearings	12	Al	Good	Thrust, constraint; bearing and lubrication requirements; alignment	Assurance testing	-	-

TABLE 3 - Continued

RELIABILITY EVALUATION

EFFECTS OF SEPARATION	UNIFORMITY OF OPERATION	CONSTRUCTION	COMPLEXITY
1. Possible binding in nozzle throat and scoring of nozzle surface. 2. Requires disconnect.	1. Should provide uniform operation. 2. Less vulnerable to high velocity transients. 3. Operation replication should be good. 4. Pulling-force increase attainable without significant increase in complexity.	1. Likely to have little variability. 2. Lead screw must be accurately built.	1. Requires guide and support for wire end of screw. 2. Requires gear drive and motor (could be redundant). 3. Screw must turn at relatively high speed. 4. Usable throat diameter smaller.
FAILURE MODES	INTERACTIONS	TEMPERATURE EFFECTS	PRESSURE EFFECTS
1. Excessive torque could bind nut in guide. 2. Gear failure. 3. Motor failure. 4. Fouling wires with screw. 5. Binding.	1. Base attached to skirt/support. 2. Requires gas supply for motor.	1. Operation of bearings, gears, and ball nut at low temperature could greatly increase torque required.	1. No significant effect.
VIBRATION EFFECTS	ADJUSTMENT REQUIREMENTS	OTHER INERTIAL FORCES	HAZARDS
1. Relatively large mass of considerable length may be susceptible to low vibrations but should not be a difficult problem.	1. Requires an alignment fixture but not as complex as bellows or multiple piston.	1. Not significant.	1. Handling: not as critical as bellows but care must be taken with screw. 2. Fire. 3. Explosion. 4. Wreck.

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TABLE 4 BELLOWS ACTUATOR EVALUATION

Item	Weight (lbs)	Mat'l	Analysis Validity	Design and System Complexity	Development Effort	Safeguards Compatibility	Remarks
Complete system	210	-	Complex: unpredictability of bellows action	Minimum number of working elements; low tolerance sensitivity; requires reactor pressurization	Problems relate to bellows pressurization of entire core, and maintenance of system seal against entire withdrawal force	Sealed nozzles aid attainment of environmental protection	Minimum space and weight requirements; maximum operating temp of 300 F set by plastic insert melting requirement
Bellows element	57 (one element)	Plastic or rubber	Low, results are narrowly restricted	Difficult to provide proper restraint; pressure deformation unpredictable; major stress on inner dia of convolution	Requires extensive engineering analysis and confidence testing; materials selection; maintaining seal at transition joints	Material environmental suitability; ineffective as fire obstacle; delays entry of hydrogenous liquids	Alternate design is pressurization of annular space between concentric bellows
System pressure seal	Include as part of support cone	Epoxy	Several credible variations	Sealing against nozzle wall tube irregularities is complex; adhering material to melt below 300 F	Reasonable examination of sealing techniques and materials	Tight seal imperative	Consider injectible and flexible epoxies
Support cone	10	Al or Mg	Good	Conform to nozzle geometry variation; contact pressure not to exceed 500 psi	Consistency with pressure seal needs	-	-
Bellows guide bushing closure	10	Al or Mg	Good	Compression stability analysis	Stability testing, bushing material compatibility	-	-

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TABLE 4 - Continued

Item	Weight (lbs)	Mat'l	Analysis Validity	Design and System Complexity	Development Effort	Safeguards Compatibility	Remarks
Retractor	15	Steel	Good	Positive engagement; force transfer to nozzle; mechanism simplicity	Assurance of loading action and engagement testing	Mandatory for retention of wires	Consider eliminating leaf spring
Bellows stop release	5	Steel	Good	Routine	Assurance testing	Bellow retention	-
Guide rods	5	Al	Good	Vibration study	-	-	-
Baseplate	9	Al or Mg	Good	Allow for S-II tank expansion	-	-	-
Structural support network	40	Steel	Good	Minimizing weight: stage attachment	Structural	-	REON interface coordination
Support cone struts	10	Al	Good	Buckling resistance	-	Seal positioning and load	-
Accumulator	20 dry 35 loaded	Al	Good	Standard item	-	Helium Presents no Fire Hazard	Optimize location
Control valves regulator, and tubing	14	Al	Good	Standard items and combination	Minimal	-	-

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TABLE 4 - Continued

RELIABILITY EVALUATION

EFFECTS OF SEPARATION	UNIFORMITY OF OPERATION	CONSTRUCTION	COMPLEXITY
1. Could bind with axial misalignment. 2. Could score nozzle inner surface. 3. Force requirements to pull wires completely. 4. Needs no disconnect for gas.	1. Does not allow for unusual force requirements; e.g., binding, since it is designed for max pressure. 2. Large back lash possibility with wire acceleration after binding. 3. Likely to exhibit wide variation in transmitted forces due to binding. 4. Reaction time thru reactor large.	1. May be difficult to build like items due to complexity in seal and bellows, and in guides. 2. Requires precision in many areas.	1. Requires a good seal which is difficult to obtain. 2. Extractor mechanism accessibility is poor. 3. Long conical section must be precise. 4. Many folds in bellows, each a potential failure candidate. 5. May need pressure control.
FAILURE MODES	INTERACTIONS	TEMPERATURE EFFECTS	PRESSURE EFFECTS
1. Open seal. 2. Open bellows. 3. Binding and cocking on guides. 4. Extractor mating. 5. Expanded bellows prior to need.	1. Creates negative pressure transients on reactor. 2. Base must attach to skirt/support. 3. Base should attach to nozzle to effectuate seal. 4. Requires gas supply thru reactor.	1. May have special bearing requirements. 2. Contraction of hypotenuse may cause bowing of guides. 3. Bellows must be free of moisture. 4. Bellows material important for low temp operation.	1. With an essentially sealed reactor the bellows may explode or inflate as it moves into space, causing misalignment.
VIBRATION EFFECTS	ADJUSTMENTS	OTHER INERTIAL FORCES	HAZARDS
1. Likely to have low frequency resonance in range of launch spectrum.	1. Essentially blind alignment to extractor head, axial centering.	1. May tend to operate under excessive loadings, causing misalignment.	1. Handling: care required to prevent bellows puncture, scoring, etc. 2. Fire: fail safe. 3. Explosion: must have interlock engagement. 4. Wreck: collapse or tear must occur above the throat. 5. Gas leak and sticking interlock pull wires.

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TABLE 5 WINDING CABLE ACTUATOR

Item	Weight (lbs)	Mat'l	Analysis Validity	Design and System Complexity	Development Effort	Safeguards Compatibility	Remarks
Complete system	326		Good	Basic elements are well proven; difficult to describe spring and cable guidance motion.	System elements: simplicity assures minimum development effort	Minimum influence	Guide tube is convenient receptacle for withdrawn wires; extraction spring is fundamentally unnecessary
Wire support retainer	10	Steel	Fair	Leaf spring type; appropriate to withstand acceleration loading; acceptable nozzle wall load distribution	Action under simulated load testing	Mandatory for wire retention	-
Retractor lock	15	Steel	Good	Mechanism simplicity, positive engagement and locking	Actuation, engagement and locking assurance testing	-	Allow for S-II tank expansion
Spring guide retainer	8	Al	Good	Alignment of motion	Description of spring motion characteristics	-	-
Extraction spring	4	Steel	Difficult	Matching load to force applied; rate of pull force application to wires	Force rate and displacement prediction analyses: confirmation	Investigate damage potential to coolant channels by transmission of spring acceleration forces through wires	Spring can be eliminated
Extraction release	5	Steel	Good	Trip under maximum load	Assurance testing	-	A simple stop if spring eliminated

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TABLE 5 - Continued

Item	Weight (lbs)	Mat'l	Analysis Validity	Design and System Complexity	Development Effort	Safeguards Compatibility	Remarks
Guide tube	70	Al	Good	Minimum weight	-	Include stop to prevent spring motion into nozzle in event of cable release	-
Baseplate	9	Al	Good	Allow for S-II tank expansion	-	-	-
Structural support network	55	Al	Complex	Minimizing weight; stage attachment; reversal of load direction	Structural test	-	REON interface and coordination
Gas motor	30	Al & steel	Good	Material selection to minimize weight; bearing and lubrication requirements	Environmental testing	-	-
Accumulator	40 dry 80 loaded	Al	Good	Standard item	-	Helium presents no fire hazards	Optimize location
Control valves, regulatory and tubing	12	Al	Good	Standard items and combination	Minimal	-	-
Drum, cable, and cable guide	13	Al & steel	-	Prevent cable fouling with positive guidance	Design selection testing	-	-

TABLE 5 - Continued
RELIABILITY EVALUATION

EFFECTS OF SEPARATION	UNIFORMITY OF OPERATION	CONSTRUCTION	COMPLEXITY
1. Likely to be best arrangement: offers minimal mechanical interference if guide cylinder can be eliminated. 2. Requires disconnect.	1. Should provide uniform operation. 2. Reel and guide must be simplified. 3. Should have good pull out force margin. 4. May have variable velocity considerations with spring and loose cable.	1. Simple to build from the viewpoint of detail past precision.	1. Spring cable arrangement may not be necessary. 2. Hole thru nozzle may have dire effect on control and operation of pull out and nozzle efficiency. 3. Cable guide at reel and cable reeling present problems. 4. Method is relatively simple.
FAILURE MODES	INTERACTIONS	TEMPERATURE EFFECTS	PRESSURE EFFECTS
1. Broken spring, cable. 2. Jammed cable. 3. Possible wire breaking due to dynamics in pull out if the spring oscillates. 4. (With 3 above-same reverse effect on core).	1. Motor drive attached to skirt/ support. 2. Requires gas or electric supply for operation. 3. Imposes little or no reverse forces.	1. Operation of motor and reel may be affected at low temperature.	1. No significant effect.
VIBRATION EFFECTS	ADJUSTMENT REQUIREMENTS	OTHER INERTIAL FORCES	HAZARDS
1. Vibrating cable could exert pulling forces that could displace pulling head if not clamped.	1. Alignment fixture: not simple with surrounding tube. 2. Requires adjustment and detenting pulling head in tube: could be a problem since there are at least two degrees of freedom.	1. Not significant.	1. Handling: not critical. 2. Fire. 3. Explosion. 4. Wreck.

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TABLE 6
WINDING TAPE ACTUATOR PARTS LIST

Item	Material	Weight/Unit	Quantity	Total Weight	Remarks
<u>Poison wire bundle</u>	-	0.98 lb	164	160.5 lbs	16 wires/bundle
Poison wires	-	25.9/gm	2620	149.6 lbs	80 inches long
Neutron poison material	B ¹⁰	5.24 gm	2620	30.3 lbs	Or rare earth oxide
Poison wire metal sheath	SS	13.88 gm	2620	80.2 lbs	
Poison wire protective coating	Teflon	6.79 gm	2620	39.1 lbs	
Poison wire bundle sheath	Teflon	10.7 gm	164	10.9 lbs	
<u>Poison wire terminal link</u>	SS	0.363 lb	164	59.6 lbs	
Terminal link protective coating	Teflon	7.0 gm	164	2.5 lbs	
<u>Wire support retainer</u>	-		1	27.4 lbs	
Retainer spring	-	7.8 lbs	1	7.8 lbs	
Spring	SS	4.5 lbs	1	4.5 lbs	
Spring anchor collar	SS	3.3 lbs	1	3.3 lbs	
Protective coating	Teflon	10 gm	1	-	
Termination retainer plate	SS	5.2 lbs	1	5.2 lbs	
Anchor ring	SS	6.6 lbs	1	6.6 lbs	
<u>Retractor lock</u>	-	2.2 lbs	1	2.2 lbs	
Retractor lock support plate	Mg	0.8 lbs	1	0.8 lbs	
Retractor lock actuator cylinder	Al	0.16 lbs	3	0.5 lbs	
Retractor lock actuator pin	SS	0.17 lbs	3	0.5 lbs	
Retractor lock actuator support clamp	Al	0.1 lbs	3	0.3 lbs	
Pull tape retainer	SS	0.1 lbs	1	0.1 lbs	
<u>Guide cylinder</u>	Mg	3.5 lbs	1	3.5 lbs	
Guide cylinder tube	Mg	3.4 lbs	1	3.4 lbs	
Guide cylinder slide pins	Mg	-	3	0.1 lbs	

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TABLE 6

WINDING TAPE ACTUATOR PARTS LIST (Continued)

Item	Material	Weight/Unit	Quantity	Total Weight	Remarks
<u>Guide cylinder release mechanism</u>	-	0.4 lb	1	0.4 lbs	
Release actuator	-	0.3 lb	1	0.3 lbs	
Release pin	SS	0.1 lb	1	0.1 lbs	
Release pin spring	SS	-	1	-	
<u>Actuation support structure</u>	SS	-	1	54.8 lbs	
Thrust tube	-	-	1	29.2 lbs	
Thrust tube housing	Mg	26.0 lbs	1	26.0 lbs	
Guide cylinder alignment key	SS	1.2 lbs	1	1.2 lbs	
Thrust tube support anchor	Mg	2.0 lbs	1	2.0 lbs	
Thrust tube support	Mg	-	1	25.2 lbs	
Thrust tube support ring	Mg	1.2 lbs	1	1.2 lbs	
Thrust tube support braces	Mg	6.5 lbs	3	19.5 lbs	
Support brace anchor	Mg	1.5 lbs	3	4.5 lbs	
Flexible pull tape	Elgiloy	0.4 lbs	1	0.4 lbs	
<u>Pneumatic drive motor</u>	-	30.6 lbs	1	30.6 lbs	
Motor	-	25.0 lbs	1	25.0 lbs	
Tape winding spool	Al	0.6 lbs	1	0.6 lbs	
Motor support bracket	Mg	5.0 lbs	1	5.0 lbs	
<u>Pneumatic accumulator</u>	-	30.0 lbs	1	30.0 lbs	
Accumulator (filled)	Al	25.0 lbs	1	25.0 lbs	20 lbs accumu- lator wt
Accumulator support	Mg	5.0 lbs	1	5.0 lbs	
<u>ACPS Control system</u>	-	12.0 lbs	1	12.0 lbs	

Total weight = 381.2 lbs

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APPENDIX A

ACPS OPERATIONAL GUIDELINES

NEUTRONIC

Normal Operation

- A. ACPS and its operation should be neutronically compatible with the engine control requirements of NERVA/RIFT during in-flight start-up.

Accidental Operation

- B. ACPS should maintain the reactor subcritical when it is reflected by and/or flooded with LH_2 , fluid hydrocarbon propellants, or water.
- C. ACPS should maintain the reactor subcritical when it is mechanically compressed, geometrically deformed, or otherwise altered by propellant detonations, conflagrations, impact, or other credible accident conditions.
- D. Guidelines B and C should be met assuming the reactor control system to be in the "poison full out" position until such time as accidental movement to this position is precluded by positive means otherwise eliminated as a credible event.
- E. If the reactor is partly disassembled, the poison component of the ACPS should maintain major core fuel regions remaining in the pressure vessel subcritical when they are reflected by and/or flooded with LH_2 , fluid hydrocarbon propellants, or water.

ENVIRONMENTAL

Normal Operation

- A. ACPS should be operable during and after exposure to local temperature extremes representative of the NERVA-RIFT environment.
- B. ACPS should be operable during and after exposure to longitudinal and transverse accelerations representative of the NERVA/RIFT environment.

- C. ACPS should be operable during and after exposure to local shock and random sinusoidal vibrations representative of the NERVA/RIFT environment.
- D. ACPS should be operable during and after exposure to zero g and to low pressures representative of the NERVA/RIFT environment.

Accidental Operation

- E. ACPS should "safe" the reactor during and after credible accidental temperature extremes.
- F. ACPS should safe the reactor during impact and after exposure to those impact pressures and decelerations which do not result in subcritical disassembly of the reactor.
- G. ACPS should safe the reactor during credible propellant detonations and after exposures to credible peak overpressures and impulse loads which do not result in subcritical disassembly of the reactor.
- H. Following impact in shallow sea water and assuming the fuel to remain essentially intact, ACPS should continue to safe the reactor, withstanding sea water immersion for a reasonable time until the reactor is recovered. Poison and encapsulation materials should be selected to reduce as much as possible the erosive and corrosive effects of sea water.

DESIGN

- A. The withdrawal mechanism of ACPS should be a self-contained and independent system. Attachments to other systems should be made only for improving reliability, for control signal initiation, and for structural support.
- B. The withdrawal mechanism of ACPS should be in the fail-safe (or disengaged) position during ground handling, transport, launch, and chemical boost stages.
- C. The ACPS control system must cause at least two independent events to occur before the poison wires can be extracted from the reactor core.

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- D. ACPS should remove the poison wires from the reactor without damaging or otherwise degrading the reactor in a time and manner compatible with the startup sequence. The complete extraction of the wires should take no more than 10 seconds.
- E. ACPS should be removed from the nozzle without damaging the nozzle or otherwise degrading its performance.
- F. The ACPS system should remove and store the poison wires in such a way that the reactor can go critical before separation of the S-II and SN stages.
- G. The extracted wires may remain in the nozzle and nozzle throat area until separation of the S-II and SN stages.
- H. If the S-II and SN stages are separated before arming of the wire extraction mechanism, the poison wires will remain in the reactor core.
- I. The poison wire retaining mechanism in the throat of the nozzle should prevent or retard the entrance of hydrogenous material into the reactor core through the nozzle.
- J. ACPS should be removed from the engine and nuclear stage, without damaging them or otherwise degrading their performance. All removable components of the ACPS will be removed with the S-II stage upon separation of the S-II and SN stages.
- K. ACPS weight should be as low as possible commensurate with functional performance and reliability. The tradeoff between weight, functional performance, and reliability will be determined by an apportionment of the reliability goal.

RELIABILITY

Normal Operation

- A. ACPS reliability should be compatible with that of the engine subsystem. This will be established by a reliability apportionment of the reliability goal for the engine.

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- B. Component redundancy shall be utilized when necessary to meet the ACPS apportionment of the reliability goal.

Accidental Operation

- C. ACPS should have maximum reliability for safing the reactor passively during and after credible accidental conditions potentially causal to nuclear incidents.

RANGE SAFETY

- A. ACPS poison components should be inserted in the engine prior to and at all times when the nozzle is attached to the reactor.
- B. ACPS should safe the reactor during all operations subsequent to engine assembly including ground handling, stage and vehicle assembly, vehicle transport, launch, and up to the point of arming and extraction just prior to planned in-flight criticality.
- C. Provisions should be made for access to and inspection of the visible areas of the ACPS at any time in the ground handling sequence prior to launch, providing there are no other systems or environmental obstructions.

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APPENDIX B
TENTATIVE SPECIFICATION
ANTICRITICALITY POISON SYSTEM

1. SCOPE

This specification defines the requirements for a system to maintain noncriticality of the assembled RIFT reactor in all environments, and to control the removal of the system components at a predetermined stage of the RIFT flight.

2. APPLICABLE DOCUMENTS

The following documents of the issue in effect at the time of final assembly form a part of this specification to the extent specified herein.

WANL-TME-396, Preliminary Model Specification - NRX-A

WANL-TME-476, NERVA Reactor Environment

WANL-TNR-088, NERVA Nuclear Subsystem Reliability and Quality Assurance Program Plan

3. REQUIREMENTS

3.1 Compliance. - No change shall be made from the requirements of this specification without obtaining the prior approval of WANL.

3.2 Materials

NOTE

This materials section of the specification applies to an anticriticality poison system using a winding tape withdrawal actuator.

3.2.1 Poison Wires

3.2.1.1 Poison Material. - The poison wires shall contain a material such as B_{10} , Eu_{203} , Sm_{203} , Gd_{203} , or other neutron poison material which will reduce the reactor neutron flux. The poison material shall be selected on the basis of maximum neutron flux degradation, corrosion and erosion resistance, high temperature stability, and compatibility with the material.

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3.2.1.2 Poison Material Sheath - The poison encasement material shall be capable of withstanding long term immersion in sea water without significant corrosion. It shall be sufficiently ductile to enable easy extraction of wires from the reactor coolant channels and without damage to the channels or the columbium coating. It shall be sufficiently strong that the wires will not break on extraction or under impact conditions. It must resist erosion, and be compatible with the poison material. An austenite stainless steel appears to be one of the better materials for this application.

3.2.1.3 Poison Wire Protective Coating - A protective coating on the poison material sheath shall prevent damage to the reactor core and core exit area. This coating shall be a soft plastic material at least 0.010 inch thick. TFE Teflon tubing is a suitable material. Teflon provides an operating temperature range from -420 F to 500 F, suffers practically no vapor disposition in a vacuum, has an ultimate tensile strength of 3500 to 4500 psi, and has very low frictional coefficients. Teflon tubing can readily be prestretched and heat shrunk to adhere closely to the wire. The material has no liquid state. It deforms between 530 F - 560 F and sublimates at 570 F. The deformation process will tend to hold the wires in the core in case of fire.

3.2.2 Poison Wire Termination Linkage - A poison wire termination linkage shall connect the poison wire to the wire support retainer and shall allow for articulation in the movement of the wires through the nozzle. This linkage may also assist in retaining the wire in the reactor core by acting as a rigid guide. The basic linkage material must have sufficient strength to retain the wires under all operational and accidental conditions. The material must have high temperature stability and be corrosion resistant. Stainless steel is probably a satisfactory material for this application. The termination linkage must be coated with

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Teflon or other suitable plastic to prevent possible damage to the reactor nozzle during the extraction procedure. The brazing or welding material used for attaching the wires shall be capable of withstanding temperatures as near as possible to that of the basic materials. The welding or brazing shall also have corrosion resistance.

- 3.2.3 Wire Support Retainer - The wire support retainer shall be fabricated from stainless steel or other high temperature corrosion resistant material so that it can act as a fire barrier in the throat of the nozzle. The spring and spring anchor collar or other retaining device must be coated with plastic or epoxy to prevent possible damage to the nozzle throat area.
- 3.2.4 Retractor Lock Support Plate - The retractor lock support plate shall support the actuator cylinders. A magnesium alloy is probably the best material for this component.
- 3.2.5 Retractor Lock Actuator Cylinder - The material selection for the actuator cylinders shall depend on the pneumatic pressure, the frictional compatibility of the pins, and the cantilevered load reflected by the pins during the wire extraction operation. Aluminum has been tentatively selected for this purpose. The slide pins should be stainless steel.
- 3.2.6 Guide Cylinder - The guide cylinder will support the retractor lock before arming engagement and will guide the wire support retainer and the wires during extraction. Magnesium is one of the better materials for this purpose.
- 3.2.7 Guide Cylinder Release Mechanism - The guide cylinder release mechanism will free the guide cylinder after the retractor lock engagement. The material requirements will be dictated by the actuator operational mode which may be either pneumatic or electrical.
- 3.2.8 Thrust Tube - The thrust tube supports and guides the retractor lock and houses the extracted poison wires. A magnesium based alloy has been tentatively selected as the lightest suitable material for the thrust tube and its support.

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3.2.9 Tape - Elgiloy, a product of the Elgin National Watch Company, has been selected as the winding tape material. Elgiloy has an ultimate strength of up to 368,000 psi, a yield of 280,000 psi, and an elastic modulus of 2.95×10^7 . Elgiloy tape bands have been used up to 1.8×10^8 cycles without breakage. The thickness of this material should be minimized to reduce the bending moment. Material 0.010 inch thick can be readily wound on a 2 inch diameter spool. Cold reduction to 85 percent and heat treating considerably improves the tensile characteristics. Information on low temperature tensile and flexibility characteristics of this material is needed.

3.2.10 Pneumatic Drive Motor System

3.2.10.1 Pneumatic Drive Motor - Special light weight pneumatic motors have been developed for space application.

3.2.10.2 Winding Tape Sheave - The winding tape sheave shall be made of aluminum.

3.2.10.3 Motor Support Bracket - The motor support bracket shall be made of magnesium.

3.2.10.4 Accumulator - High pressure accumulators are usually fabricated from aluminum alloys. The support bracket could be magnesium.

3.3 Environmental Requirements

3.3.1 Fluid Environment - Anticriticality shall be maintained in air, nitrogen, liquid or gaseous hydrogen, and in water. The retractor mechanism shall be operational in air, nitrogen or hydrogen, in mixtures of these, and in a vacuum.

3.3.2 Temperature - The system shall be operational in the temperature range - 80 F to 160 F.

3.3.3 Pressure - The system shall be operational in the pressure range 795 mm to 10^{-8} mm Hg.

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3.3.4 Atmosphere

3.3.4.1 Humidity - The system shall be operable in the humidity range 0 to 100 percent relative humidity.

3.3.4.2 Air Contamination - The system shall be operational when exposed to a marine environment (salt droplets in air), to severe rainfall, airborne sand, and dust.

4. PERFORMANCE CRITERIA

4.1 Loading

4.1.1 Sustained - Along longitudinal axis, 5g fore and 1.2g aft.

4.1.2 Shock - Up to 2.5g axially and 1.8g laterally.

4.1.3 Vibrational - Steady state, 7g; transient, 14g. (See figures 2 and 3, WANL-TME-567.)

4.1.4 Rotational (around thrust axis) - To an angular acceleration of 15 deg/sec² and to an angular velocity of 10 deg/sec. (Refer to WANL-TME-476, p 15.)

4.2 Attitude - ACPS shall be operational in any attitude of the reactor.

4.3 Reactor k_{eff} - ACPS shall maintain a reactivity of $k_{eff} < 0.95$ with the core filled with water and with the control drums in the maximum reactivity position.

4.4 Reliability - The reliability will be compatible with that of the NERVA engine subsystem. Reliability will be established by an apportionment of the reliability goal for the engine, and is tentatively set at 99.5 percent.

4.5 Withdrawal Time - The system shall be capable of completely removing the poison wires from the core in 10 seconds or less.

4.6 Engagement - Disengagement - The mechanism for engaging the poison system and the reactor device must also be capable of readily disengaging them.

5. DESIGN CRITERIA

5.1 General

5.1.1 The weight of the system must be a minimum consistent with reliability and good design.

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5.1.2 ACPS must function as a poison system during transportation of the reactor and preparation for launching, as well as during preflight and flight.

5.1.3 The second and reactor stages shall deviate no more than 0.5 degrees from the longitudinal axis before the two stages are separated more than 8 feet.

5.2 Poison Wire - Pull Head Assembly

5.2.1 The nuclear poison should minimize the number of poison elements required to achieve the objective stated in Section 4.3.

5.2.2 The poison wire-pull head assembly must not damage the nozzle. A plastic liner may be fitted and left in the nozzle chamber and throat if it has a melting point of 300 F maximum.

5.2.3 The poison wires shall produce minimum friction with the channel surfaces when being retracted and must not cause core damage.

5.2.4 The poison wires shall not abrade during withdrawal, or act in any way to deposit material in channels which could plug the channels.

5.2.5 The poison wires shall remain in the core if the second stage is separated prematurely from the nuclear reactor.

5.2.6 The poison wires shall remain in the core if the reactor is damaged by fire or by mechanical shock.

5.2.7 The poison wires shall be inserted only into the coolant channels completely traversing the core in a straight line.

5.2.8 The poison wires shall not touch the orifice jets.

5.2.9 The retainer spring or other supports shall be capable of preventing deflection of the poison wire extensions due to an inertial loading after launch.

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5.3 Retractor Mechanism

- 5.3.1 To ensure avoidance of premature retraction of poison wires, at least two controls must operate sequentially to actuate the retractor mechanism.
- 5.3.2 The system must be capable of withdrawing the poison wires from the core into the nozzle before the separation of stages during the RIFT flight.
- 5.3.3 The structural supports for the retractor mechanism may be mounted on the S-II manhole or attached to other structural members of the S-II stage.
- 5.3.4 In the RIFT flight, the retractor mechanism, poison wires, and supports must be attached to the second stage after separation from the nuclear rocket stage.

5.4 Nozzle. - The design shall limit the load on the throat area of the nozzle to 500 psi.

5.5 Interstage Area

- 5.5.1 The tentative design provides 10.4 inches between the second stage dome and the nozzle dome and the nozzle exit plane. The design must accommodate a two inch deflection of the second dome due to pressurization of the second stage.
- 5.5.2 A catwalk may be required in the interstage area for workers engaged in preparation for launching.

6. PROCEDURE FOR ASSEMBLING

- 6.1 During assembly of the core with the nozzle the poison wires shall be inserted into the cooling channels of graphite-uranium fuel elements as required to avoid criticality.
- 6.2 At the proper stage of reactor assembly, the extensions of the poison wires shall be attached to the wire support retainer.
- 6.3 The nozzle shall be attached to the reactor pressure vessel with the wire support retainer fitting into the throat of the nozzle.

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- 6.4 During final assembly of the RIFT complex, the retractor lock shall be positioned to be capable of engaging the wire support retainer.
- 6.5 If criticality tests are performed after insertion of the wires the nozzle will be removed and the poison wires re-inserted. The poison wires must be straightened and re-inspected before re-insertion into the core.

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APPENDIX C
TEST RESULTS

INTRODUCTION

As part of the development of the design of ACPs, series of wire pull tests were conducted. The objectives of these tests are described in separate reports.³ This appendix presents data obtained from the tests and analyzes the data.

PRELIMINARY TESTS

Preliminary tests were conducted to demonstrate the feasibility of extracting poison wires from the reactor and to establish basic operating parameters. The more significant results of these tests are:

- 1) It is feasible to insert several thousand poison wires into the reactor core and to extract them through the nozzle.
- 2) The wires can be inserted and extracted without damage to the core coolant channels and the columbium coating at the reactor core exit, and without damage to the wires themselves.
- 3) Bare metal wires abrade the coolant channels and damage the columbium coating during extraction.
- 4) Wires sheathed with 0.010 inch of Teflon can be extracted without damage to any components.
- 5) Soft wires and very rigid wires cause damage during extraction.
- 6) Wires of 0.050 inches solid untempered 304 stainless steel with Teflon sheaths offer minimum frictional resistance to extraction. This is due to the bending characteristics of this wire. Harder and softer wires considerably increase frictional loads and thus the possibility of core and coating damage.

3

WANL-TME-603, Selection of Material, Number & Distribution of Poison Wires for the Anticriticality Poison System, and WANL-TME-546, Feasibility of a Full Core Nuclear Poison System for Use During RIFT Launch Operations.

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7) The force required for extraction increases considerably for wires inserted close to the outer radius of the core. The approximate peak load per stainless-steel Teflon-coated wire at the center of the core is 0.1 lb, 1.0 lb at the 31.2 centimeter radius, and 1.8 lbs at 43 centimeters, which is the outer radius of the core. The average peak load per wire for a number of wires distributed evenly through the core is approximately 1 lb.

8) During extraction, pull forces fluctuate. The initial load is high due to the static friction of the wires in the center of the core. As these wires slide the load decreases, and then peaks again because of the static friction of the wires in the outer radii. Figure C-1 plots the fluctuation of load with time for typical wires distributed evenly over the reactor core face.

The load then decreases rapidly to a near steady state as all wires move, producing only sliding friction. Approximately 2 inches before the end of extraction the load rises sharply to a maximum peak. This is due to the gouging of the wires on the coolant channels and the increased bending moment at the wire ends. The peak load occurs in the last 0.5 inch of a wire. The 2 inch spread is caused by the wires exiting at different times. The wires are approximately the same length so that exit time depends on location of the wire in the core.

RECENT TESTS

General

The following information was derived from tests mostly conducted between 5 November 1963 and 31 December 1963. In these tests all wires were extracted at approximately 6 inches per second, unless otherwise specified. The test rig is described in TME-546, Feasibility of a Full Core Nuclear Poison System for Use During RIFT Launch Operations. Figure C-2 is a program test sheet which shows the location and number of dummy fuel clusters available for pull tests. The final poison wire design has not been defined, and most of the tests used Teflon coated solid stainless steel wires to simulate the test loads. These wires were inserted approximately 58 inches into the reactor core.

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Figure C-1. Fluctuation of Load with Time for Typical Wires

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Figure C-2. Program Test Sheet

Accuracy of Test Data

High accuracy of test data was not required although it was desirable to know what degree of accuracy was obtained. A standard XY recorder with a response time of approximately two tenths of a second was used to record the pull force data. The load sensing element was a wheatstone bridge arrangement of strain gages on a segment of the pull shaft.

To check the reading accuracy a second set of strain gages was placed on the pull sensor and both sets calibrated for load characteristics on a Baldwin tensile machine. Comparative resistance loads were made up for rechecking the recorders. The XY recorder and an oscillograph were calibrated for readings from the test resistors. Pull test number 1-A was then conducted:

1) Calibration run (no wire load):

Indications were identical on both recorders within the reading accuracy.

2) Wire pull tests:

	<u>Initial Loads (lbs)</u>	<u>Second Peak Load (lbs)</u>	<u>Median Load (lbs)</u>	<u>Load 2 in. From End (lbs)</u>	<u>Final Peak Load (lbs)</u>
XY recorder	150.6	167.3	119.2	105.9	360.3
Oscillograph	<u>206.8</u>	<u>184.0</u>	<u>118.9</u>	<u>102.5</u>	<u>406.1</u>
Difference	27%	9%	---	---	11%

Under steady state conditions the loads were identical within reading and calculation accuracy. The slow response time of the XY recorder produced significantly low readings under transitory conditions. The high percentage difference for the initial load was probably due to the inertia of the XY recorder and a momentary reversal of load direction which showed up on both plots.

Except for the starting torque required of the drive motor, these errors would be of little significance in testing a final system design. The period of overloads is so short that the inertia of the extraction mechanism would tend to integrate forces to a greater extent than the XY recorder.

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Reproducibility of Test Data

The reproducibility of data was analyzed to determine the accuracy of the tests. Comparisons were also made between tests using the same number and the same radial location of wires but with the wires rotated 90 degrees about the face of the core. Table C-1 lists the results of these tests.

The average variation in loads for any set of repeated tests ranged from 4.9 percent to 8.3 percent. The overall average difference between repeated tests was 7.2 percent. Difference in placement orientation radially around the core did not seem to have any appreciable effect. The variation in data from repeated tests can be attributed to:

- 1) Reading errors -- 0.1 inch graduations on the XY recorder readout sheets represent approximately seven pounds in pull force. Reading errors were significant especially for low absolute values.
- 2) Variation in frictional forces -- The wires clustered in different patterns as they passed through the simulated nozzle throat, which varied the frictional load.
- 3) Reuse of wires -- For economy the same wires were used many times. The wires were straightened by pulling beyond the yield point. Ends clamped during the straightening process were cut off to eliminate rough surfaces. Thus, wires were not uniform in cross section, in flexural strength, or in length, all of which contributed to variation in load readings.
- 4) Wire angle path variation -- The wires in the center of the core were aligned in a straight path; those in the outer radii had to be bent to fit through the simulated nozzle throat. The flexibility of the wires prevented exact duplication of their positions, and changes in wire position shifted the timing of the transition from static to sliding friction and other peak loading from one test to another.

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TABLE C -1 REPRODUCIBILITY OF TEST DATA

Test	Total Wires	Cluster Locations	Begin. Load (lbs)	Second Peak (lbs)	Load 2 in. From End (lbs)	Final Peak (lbs)	Average Difference
2-A							
Run 1	60	1, 4, 7, 10	58.9	49.6	32.5	121.0	
2-A							
Run 2	60	1, 4, 7, 10	65.8	46.4	31.9	119.9	
Difference			6.9	3.2	0.6	1.1	
% difference			10.5%	6.5%	1.8%	0.9%	4.9%
3-A							
Run 1	30	4, 10	36.7	24.9	15.9	51.3	
3-A							
Run 2	30	4, 10	38.8	26.3	17.3	59.6	
Difference			2.1	1.3	1.4	8.3	
% difference			5.4%	5.0%	8.1%	13.9%	8.1%
4-A							
Run 1	30	1, 7	34.7	28.4	15.9	55.4	
4-A							
Run 2	30	1, 7	35.3	28.4	20.3	61.0	
Difference			0.6	0	4.4	5.6	
% difference			1.7%	0	21.7%	9.3%	8.2%
4-A	30	1, 7	34.7	28.4	15.9	55.4	
3-A	30	4, 10	36.7	24.9	15.9	51.3	
Difference			2.0	3.5	0	4.1	
% difference			5.5%	12.3%	0%	7.4%	6.3%
3-6	180	1-12	168.7	164.0	88.7	344.7	
1-A	180	1-12	150.6	167.3	105.9	360.3	
Difference			18.1	3.3	17.2	15.6	
% difference			10.8%	2.0%	16.2%	4.3%	8.3%
Difference average %			6.8%	5.2%	9.6%	7.1%	

Overall average difference: 7.2%

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5) Other factors -- Conditions such as variation in guide and bearing friction, minor fluctuations in pull rate and vibratory forces contributed to the differences in readings.

All these variables will be present in an operating system. Further analysis of the effects of temperature, vibration, reduced pressure, acceleration forces, etc, will have to be investigated. A margin of pull force to accommodate these unpredictable factors will have to be included in any design.

Effects of Different Ratios of Wires on Pull Loads

The maximum number of wires used in any single pull test was 695. The present system design requires more than 2600 wires. A number of tests were conducted to determine whether increasing the number of wires linearly increases the pull load.

Tests 7A, 8A, and 9A used different numbers of wires but with proportionate radial distribution; i.e., all tests simulated an even distribution of wires per unit area throughout the core. The calculated pull-force ratios of these tests were:

Test 7A -- 0.50,

Test 8A -- 1.00, and

Test 9A -- 0.25.

The results of these tests were:

Test	Total Wires	Cluster Locations	Begin. Load (lbs)	Second Peak Load (lbs)	Load 2 in. From End (lbs)	Final Peak Load (lbs)
7-A	315	1, 3, 4, 6, 7, 9, 10, 12, 14, 17, 18, 20, 23, 24, 25, 28, 31, 34, 37, 40, 43	178.1 <u>2</u> 356.2	154.5 <u>2</u> 309.0	108.1 <u>2</u> 216.2	293.1 <u>2</u> 586.2
8-A	615	All except 27, 29, 33, 35, 38, 41 - 30 wires in 3, 5, 9, 11	352.0	350.7	221.8	554.4
9-A x4 4(9-A)	150	1, 4, 7, 10, 15, 19, 23, 26, 32, 39, 42, 43 - 7 wires in 39 & 42, 1 wire in 43	81.4 <u>4</u> 325.6	65.8 <u>4</u> 263.2	45.7 <u>4</u> 182.8	132.4 <u>4</u> 529.6

The comparisons of the pull force loads of tests 7A and 9A with 8A are:

Test	Multiple Ratio	Begin. Load (lbs)	Second Peak Load (lbs)	Load 2 in. From End (lbs)	Final Peak Load (lbs)	Average Difference
7-A	2	356.2	309.0	216.2	586.2	
8-A	1	352.0	350.7	221.8	554.4	
Difference		- 4.2	+41.7	+ 5.6	-31.8	
% difference		1.2%	11.9%	2.6%	5.4%	5.3%
9-A	4	325.6	263.2	182.8	529.6	
8-A	1	352.0	350.7	221.8	554.4	
Difference		26.4	87.5	+39.0	+24.8	
% difference		7.5%	24.9%	17.5%	4.5%	13.6%
Overall average		4.4%	18.4%	10.0%	5.0%	9.5%

The only pattern shown by these results is that larger ratios give increased comparative errors. This is to be expected because the multiplier of a number gives the same multiplier of the error.

Other tests were conducted with wires located at specific radii in the core to determine the average unit pull force of a wire at any specific radial location. The following tabulation compares these unit pull forces with pull forces for wires distributed evenly throughout the core. The multiplication factors are used for comparison purposes.

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Test	Total Wires	Cluster Locations	Begin. Load (lbs)	Second Peak Load (lbs)	Load 2 in. From End (lbs)	Final Peak Load (lbs)	Average Difference
1-A	180	1 thru 12	150.6	167.3	105.9	360.3	
12-A	180	13 thru 24	62.4	66.5	57.5	210.0	
13-A	180	25 thru 36	52.7	47.8	25.6	58.2	
14-A	90	37 thru 42	11.1	14.6	7.6	16.6	
1-A (1.33)			201	222	141	467	
12-A			62.4	66.5	57.5	210.0	
13-A (.67)			35.1	31.8	17.1	38.8	
14-A (.67)			7.4	9.7	5.1	11.1	
Sum			305.9	330.2	220.7	726.9	
8-A			352.0	350.7	221.8	554.4	
Difference			+46.1	+20.5	+ 1.1	-172.5	
% difference			13.1%	5.7%	0.5%	23.7%	10.8%

The comparison shows that the average force per unit wire cannot be extrapolated to accurately determine full core peak loading. This is due to the shift in time of occurrence of maximum force. The differences in final-peak loads clearly indicate that an even distribution of wires throughout the core spreads the peak loads over a longer period and thus reduces the magnitude of the total peak load.

These tests also show that there would be considerable error in extrapolating full-wire-complement peak load from the test data obtained to date. A full complement of poison wires must be tested to determine the magnitude and distribution of load forces, and to determine the fluctuation in force loads.

Effects of Rate of Pull on Load Distribution

The ACPS Operational Guideline, Appendix A, requires extraction of the poison wires in 10 seconds or less. The early wire pull tests were conducted on a basis of 20 second extraction time. A number of these tests were repeated using a 10 second period to determine what effects the increased rate of pull would have on pull forces. The following tabulation compares data from the two sets of tests.

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Test	Total Wires	Cluster Locations	Pull Rate	Begin. Load (lbs)	Second Peak Load (lbs)	Load 2 in. From End (lbs)	Peak Load (lbs)	Average Difference
1-A	180	1 thru 12	10 sec.	150.6	167.3	105.9	360.3	
26	180	1 thru 12	20 sec.	200.0	178.2	98.3	248.9	
Difference				+49.4	+10.9	-7.6	-111.4	
				24.7%	6.1%	7.2%	30.9%	17.2%
12-A	180	13 thru 24	10 sec.	62.4	66.5	57.5	210.0	
27	180	13 thru 24	20 sec.	61.6	76.0	56.0	115.6	
Difference				-.8	+10.5	-1.5	-94.4	
				1.3%	13.8%	2.6%	44.9%	15.6%
13-A	180	25 thru 36	10 sec.	52.7	47.8	25.6	58.2	
29	180	25 thru 36	20 sec.	48.0	57.3	24.0	44.0	
Difference				-4.7	+9.5	-1.6	-14.2	
				8.9%	16.6%	6.2%	24.4%	14.0%
14-A	90	37 thru 42	10 sec.	11.1	14.6	7.6	16.6	
30	90	27 thru 42	20 sec.	16.7	30.0	8.7	15.3	
Difference				+5.6	+15.4	+1.1	-1.3	
				33.5%	51.4%	12.7%	7.8%	26.4%
Overall average				17.1%	22.0%	7.2%	27.0%	18.3%

The rate of pull seems to have small effect on pull forces except on final peak load. Most loads are frictional and are independent of rate of motion. The final peak load results from a lever action producing a gouging and compression force couple on the end of the coolant channel and on the columbium coating. Preliminary calculations indicate the plausibility of forces of several thousand pounds per square inch at the end of the coolant channel. This accounts for the occasional chipping of the columbium coating. However, it should be kept in mind that a given channel was used repeatedly, and that failure probably occurred after progressive weakening of the material. Further design development on the wires is needed to reduce these forces. Use of less rigid materials and tapering of the ends of the wires are two modifications that have been considered.

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Figure C-3. Comparison of Solid Wires with Tubes

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Test Load Requirements for Poison Filled Tube Versus Solid Stainless Steel

Nuclear poison filled stainless-steel tubes with a polyethylene coating have been developed to prevent criticality of the NERVA reactor during shipment. The tubes are filled with boron carbide (B_4C) with an 80 to 85 percent packing factor. Since a similar design for the ACP5 wires is being considered, pull tests using solid stainless steel wires and the shipping wires were conducted and compared. Average values for two tests of each type are tabulated below:

Test	Total Wires	Cluster Location	Begin. Load (lbs)	Second Peak Load (lbs)	Load 2 in. From End (lbs)	Final Peak Load (lbs)	Average Ratio
5-A (B_4C filled x2.5 tubes)	24	1, 4, 7, 9	63.1 2.5 157.7	57.2 2.5 143.0	49.6 2.5 124.0	123.1 2.5 307.8	
2-A (SS wires)	60	1, 4, 7, 10	62.4	48.0	32.2	120.5	
Difference			95.3	95.0	91.8	187.3	
ratio 5-A/2-A			2.54	2.98	3.85	2.55	2.98

The results show that withdrawing the tubes requires three times the force needed to withdraw the wires. A number of factors contribute to this condition:

- 1) The tubes are coated with polyethylene and the wires with Teflon. Teflon has a much lower coefficient of friction than polyethylene.
- 2) The most important factor is that the tubes were work hardened by fabrication and straightening processes. As shown in figure C-3, stress calculations indicate that the deflection of the filled tube would be greater than the solid wire with the same materials in a normal condition. Figure C-3 also shows that filling the tubes with the highly compacted B_4C has small effect on the bending moment. If tubes are used they will have to be annealed after fabrication.

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Effects of Shortening the Wire on the Final Peak Loads

Tests were conducted to determine the effects of shortening 50 percent of the wires in the outer radii of the core by 2 inches. The following results were obtained:

Test	Total Wires	Cluster Locations	Begin. Load (lbs)	Second Peak Load (lbs)	Load 2 in. From End (lbs)	Final Peak Load (1) lbs	Final Peak Load (2) lbs
7-A	315	1-3-4-6-7-9-10-12 14-17-18-20-23-24-25 28-31-34-37-40-43	178.1	154.5	108.1	293.1	293.1
10-A	315		133.8	116.4	88.7	160.1	176.0
Difference			44.3	38.1	19.4	133.0	117.1
% difference			24.9%	24.7%	17.8%	45.5%	40.0%

Shortening the wires produced two end peak loads, which were only 20 percent higher than the beginning load. From this result it is apparent that staggering the lengths of the wires along with shaping the ends will significantly reduce the final peak controlling load and thus the pull force required for the extraction of the wires.

Extraction of Broken Wires

To determine whether broken wires would be extracted from the core ten tests were conducted using four wires each. The wires were cut six inches, twelve inches, eighteen inches, and twenty four inches from the ends. They were placed in the outermost radius of the core and pulled at a rate of six inches per second. The pull force was so small that it was not recorded. All wires were completely extracted from the core and all were retained within their Teflon sheaths. The wires separated one to two inches at the cut points due to slippage of the wires in the Teflon sheath. This should not occur in final-design wires since these will be tightly encased in Teflon.

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RESTRICTED DATA

The tensile strength of Teflon is reported to be 25,000 to 35,000 psi by the manufacturer. This would give the strength for the 0.010 inch thick tube presently contemplated as 60 to 85 pounds. As the maximum load on any one wire is approximately 2 pounds, the metal material is not at all taxed during withdrawal.

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