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**X-Ray Imaging Study**

**by**

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## 1. INTRODUCTION

The space environment in which the Space Station Freedom and other space platforms will orbit is truly a hostile environment. For example, the currently estimated integral fluence for electrons above 1 Mev at 2000 nautical miles is above  $2 \times 10^{10}$  electrons/cm<sup>2</sup>/day and the proton integral fluence is above  $1 \times 10^9$  protons/cm<sup>2</sup>/day. At the 200 - 400 nautical miles, which is more representative of the altitude which will provide the environment for the Space Station, each of these fluences will be proportionately less; however, the data indicates that the radiation environment will obviously have an effect on structural materials exposed to the environment for long durations. The effects of this combined environment is the issue which needs to be understood for the long term exposure of structures in space. At the same time, there will be substantial potential for collisions between the space platforms and space debris. The current NASA catalogue contains over 4500 objects floating in space which are not considered payloads. This debris can have significant effects on collision with orbiting spacecraft.

In order to better understand the effect of these hostile phenomena on spacecraft, several types of studies are being performed to simulate at some level the effect of the environment. In particular the study of debris clouds produced by hypervelocity impact on the various surfaces anticipated on the Space Station is very important at this point in time. The need to assess the threat of such debris clouds on space structures is an on-going activity.

The Space Debris Impact facility in Building 4612 provides a test facility to monitor the types of damage produced with hypervelocity impact. These facilities are used to simulate space environmental effects from energetic particles. Flash radiography or x-ray imaging has traditionally provided such information<sup>1</sup> and as such has been an important tool for recording damage in situ with the event. The proper operation of the system can provide much useful information with respect to parametric analysis of the hypervelocity experiment. The following report outlines the procedures developed to optimize the operation of the x-ray imaging system and its operational characteristics.

## X-Ray Imaging System

Marshall Space Flight Center's present flash x-ray system is used to calculate velocities and verify integrity of projectiles fired from the hypervelocity impact gun. In May of 1995, we began work to improve the image quality of the Hypervelocity Impact Facilities system. The flash x-ray system has three x-ray sub-systems. Each sub-system consists in a x-ray tube, tube

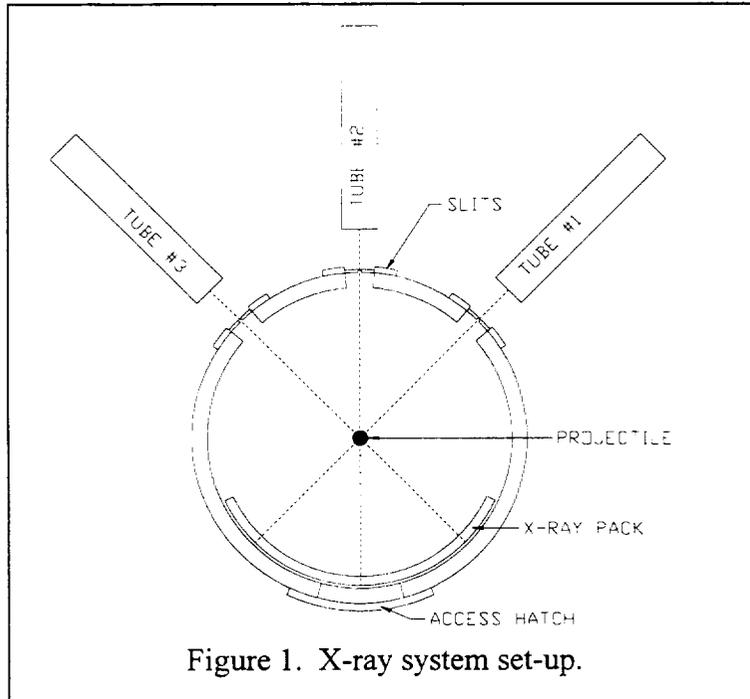


Figure 1. X-ray system set-up.

head, pulser, and delayed trigger amplifier. The tubes are placed at the same point on the impact gun spanned 45 degrees apart from each other, see figure 1 for a schematic of the system. The tubes are triggered within micro seconds of each other allowing three simultaneous images to be taken of the projectile as it travels down the chamber. The x-rays from each tube are directed through a small slit in the chamber so that there are three one inch

exposures on each x-ray sheet. Then knowing the distance the projectile traveled in the specified amount of time, a velocity is calculated.

In order to better characterize the overall performance of the system, several test images were executed at various settings, see table 1. The tests produced x-rays that were lacking contrast to the point that the projectile was not even visible and at times tube #2 failed to fire. See figures 2 and 3 on the following pages.

Test #	kV	psi	Actual/Test	Shot	Notes	Results
1	19	15	Test			Can not see projectile, too dark, over-exposure
2	19	15				Projectile in image 2, contrast inadequate
3	19	13	Actual	1717		Projectile in all 3 images, contrast not as good as shot 1718
4	17	13	Actual	1718		Contrast better, projectile only seen in 1st image, tube #2 did not fire, image 3 no projectile
5	15	13	Actual	1719		No image at all, tubes did not fire, no x-ray
6	23	15	Test		One 5 mil sheet of lead behind x-ray film	Lines visible but no projectile, projectile might not have been in field of view
7	20	15	Test		One 5 mil sheet of lead behind x-ray film kV did not zero when fired	Good contrast, lines in all images, projectile in image 2
8	21	13	Test		One 5 mil sheet of lead behind x-ray film	Lower contrast as compared with Test 11
9	21	13	Test		Removed lead, kV did not zero when fired	X-ray too dark, no contrast, fuzzy edges
	21	13.5			bumped nitrogen up, refired, kV didn't zero	
	21.75	13			increase to 21.75 kV, system fired	
10	17	8	Test		No fire (kV did not zero)	X-ray too dark
	18	8			No fire (kV did not zero)	
	19	8			No fire (kV did not zero)	

Table 1. Characterization tests

Due to the age of the system, the factory was contacted to insure no changes or modification to the overall system needed to be made and for any possible new documentation. Upon calling, we were notified that Hewlett Packard sold their flash x-ray systems to Physics International(510-577-2026) and Physics International would provide any necessary support. Physics International had several recommendations for better performance of the system. Some of their recommendations for increasing the contrast included increasing the current, if possible, and installing three separate gas regulators, one per tube. They also stated that air would be a much better gas than nitrogen because air produces a more accurate no fire curve. The technical assistants believed the cause of tube #2 not firing was due to the gas pressure being too high. They recommended performing prefire and no fire curves for each tube independently, due to the possible minor differences in the tubes.

A no fire and prefire curve was performed in order to attain an operational curve for each x-ray tube. To perform the prefire curve, a dummy load was placed inside the tube so that there would not be any unnecessary wear on the tube head. Once the dummy tube was in place the charge cable were removed from the other two units. The nitrogen was set and the charging voltage was slowly raised until the tube prefired, discharging without pressing the trigger. The run was repeated to insure a true prefire, then documented as a true prefire data point. The nitrogen level was then raised and another data point was attained. A total of four data points were taken for

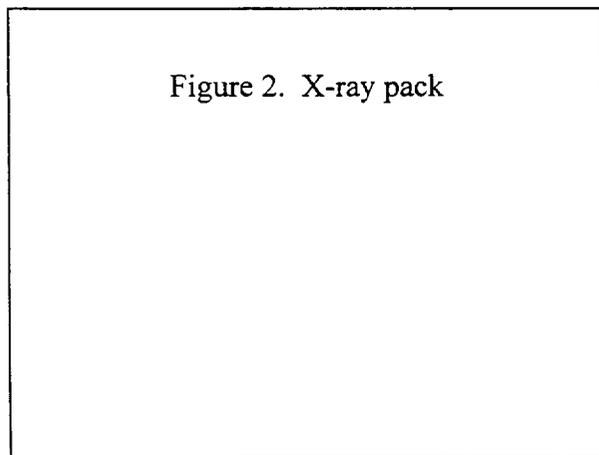


Figure 2. X-ray pack

each tube. See the figures 5 and 6 on the following pages for the prefire curves and resulting operational curve. As seen in the chart there are slight variances in the three curves. The maximum variation appears to be around 15 psi, where the charging voltage differs by 1 kV. Due to this variation being so minor, it was felt that it was not necessary to implement three separate nitrogen regulators. Now that we had

attained the operational curves, several steps were taken to improve the contrast of the x-rays.

These steps included replacing the fluorescing sheets, adding a 5 mill sheet of lead behind the x-ray film, and adjusting the keV and Nitrogen pressure. The fluorescing sheet apparently have never been replaced as far as anyone could remember. And adding the lead sheet behind the x-ray prevented any back scatter of the x-rays. The combination of actions corrected the low contrast problem and tube #2 was firing when triggered. Now that it appeared that the contrast was sufficient, shots #1731, 1732, and 1733 were performed and were added to the operational curve chart to see where they fell on the operational curves, see figures 7, 8, and 9 on the following pages.

# PREFIRE AND OPERATING CURVES FOR TUBES #1, #2 & #3

OPERATIONAL CURVE IS 20% DOWN FROM PREFIRE CURVE

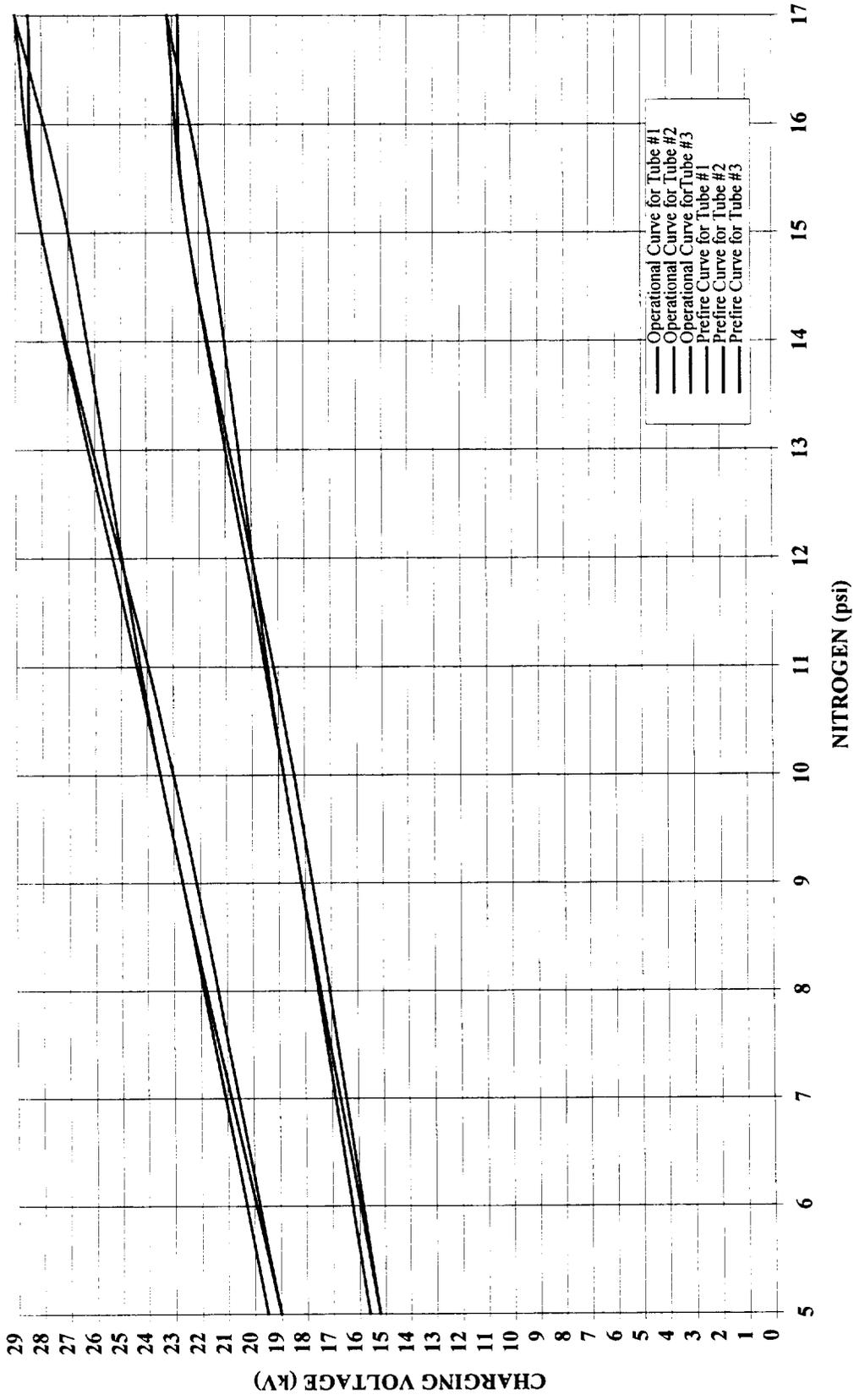
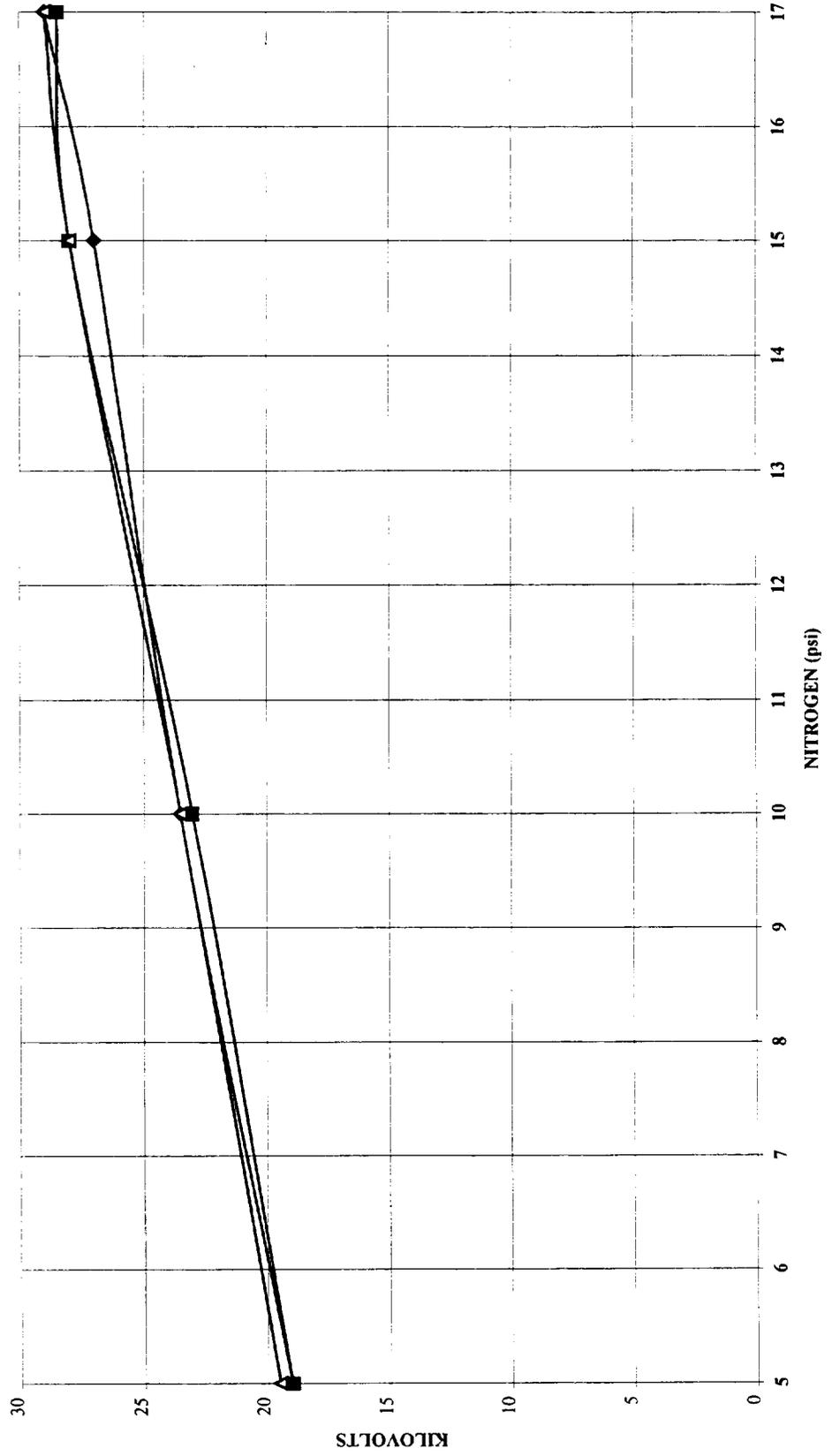


Figure 3. Prefire and operational curves for tubes 1, 2, and 3.

COMPARISON OF PREFIRE CURVES



◆ Prefire Curve for Tube #1    ■ Prefire Curve for Tube #2    ▲ Prefire Curve for Tube #3

Figure 4. Exploded view of the operational curves.

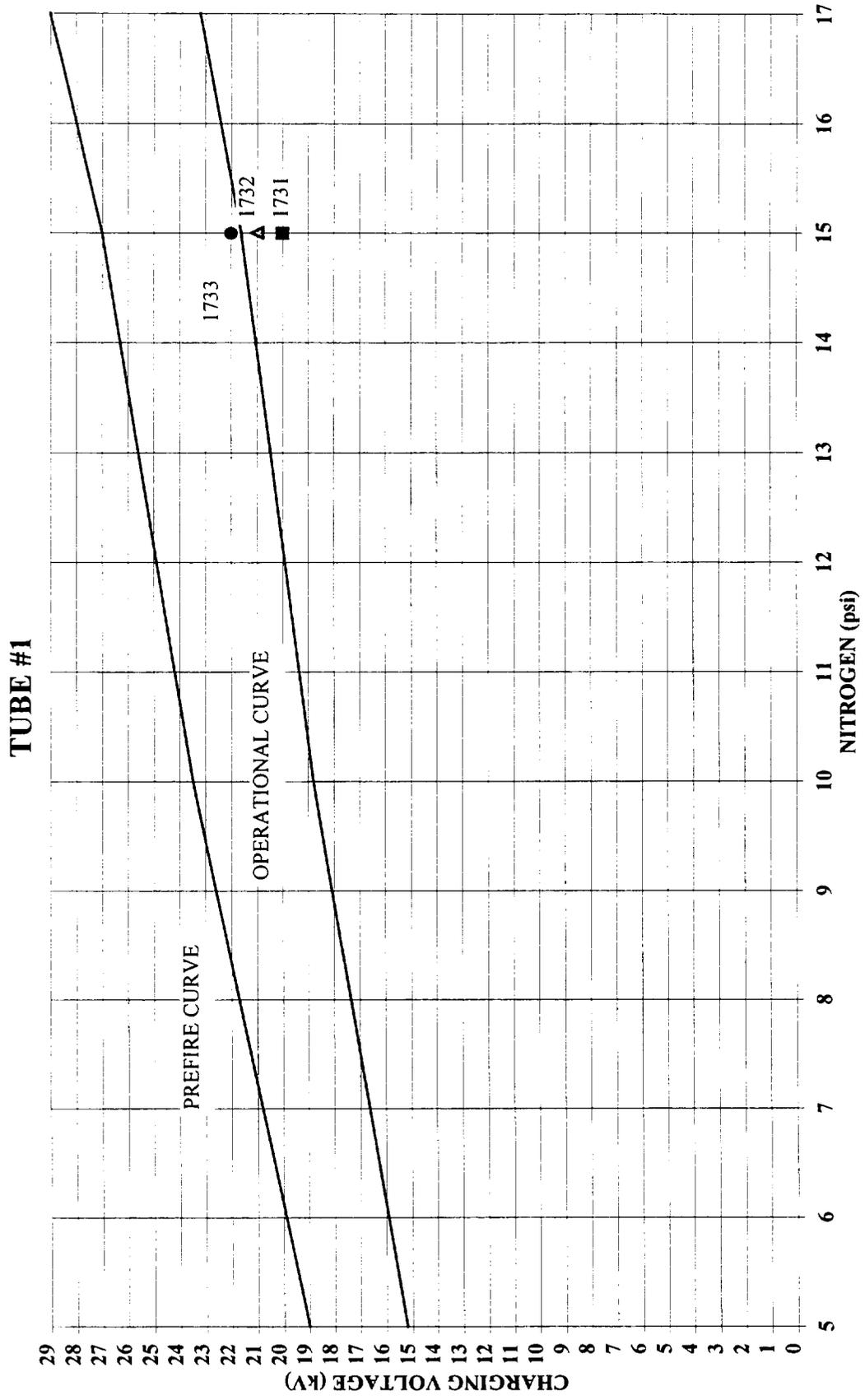


Figure 5. Shots 1731, 1732, and 1733 as compared to the operational curve for tube #1.

# TUBE #2

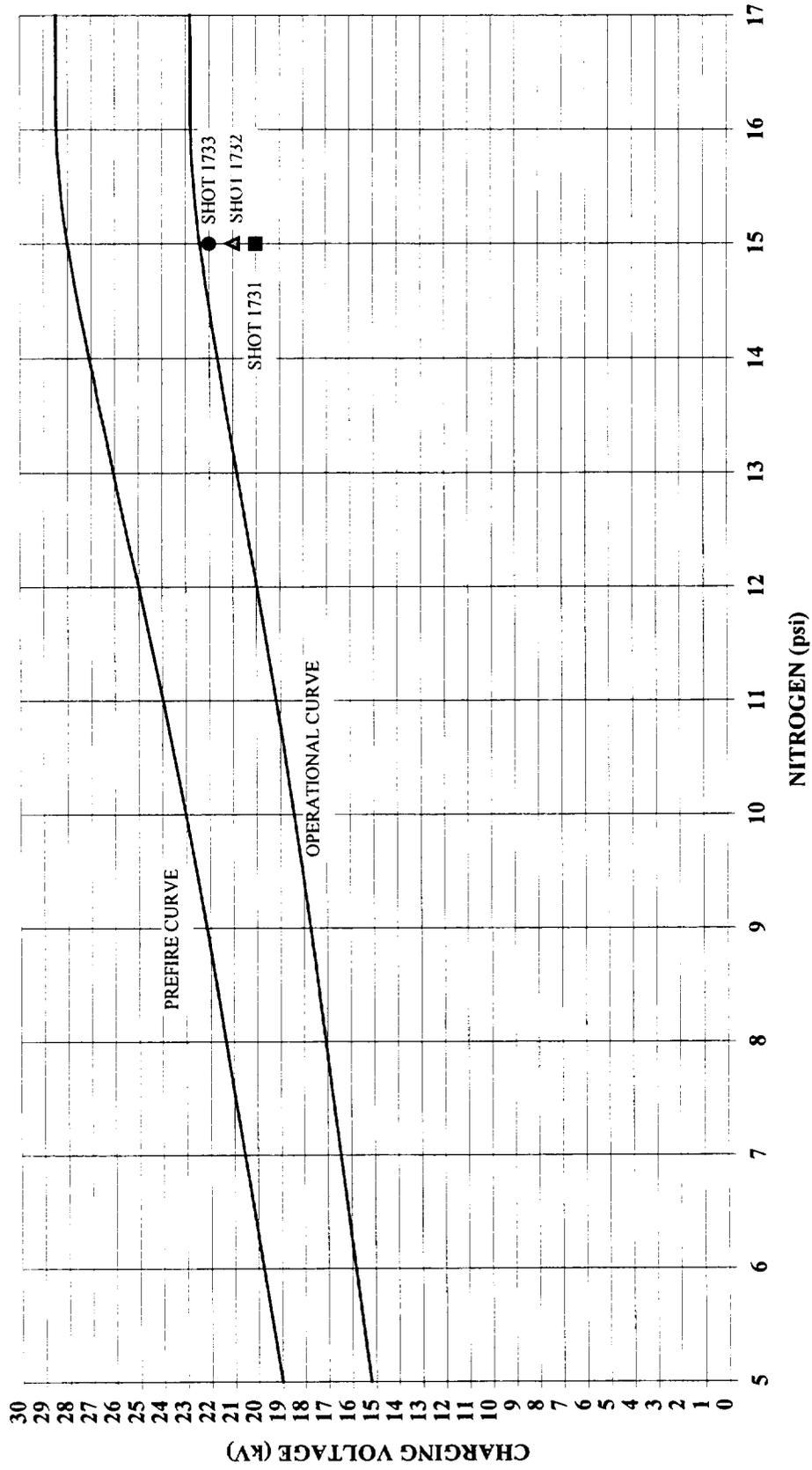


Figure 6. Shots 1731, 1732, and 1733 as compared to the operational curve for tube #2.

# TUBE #3

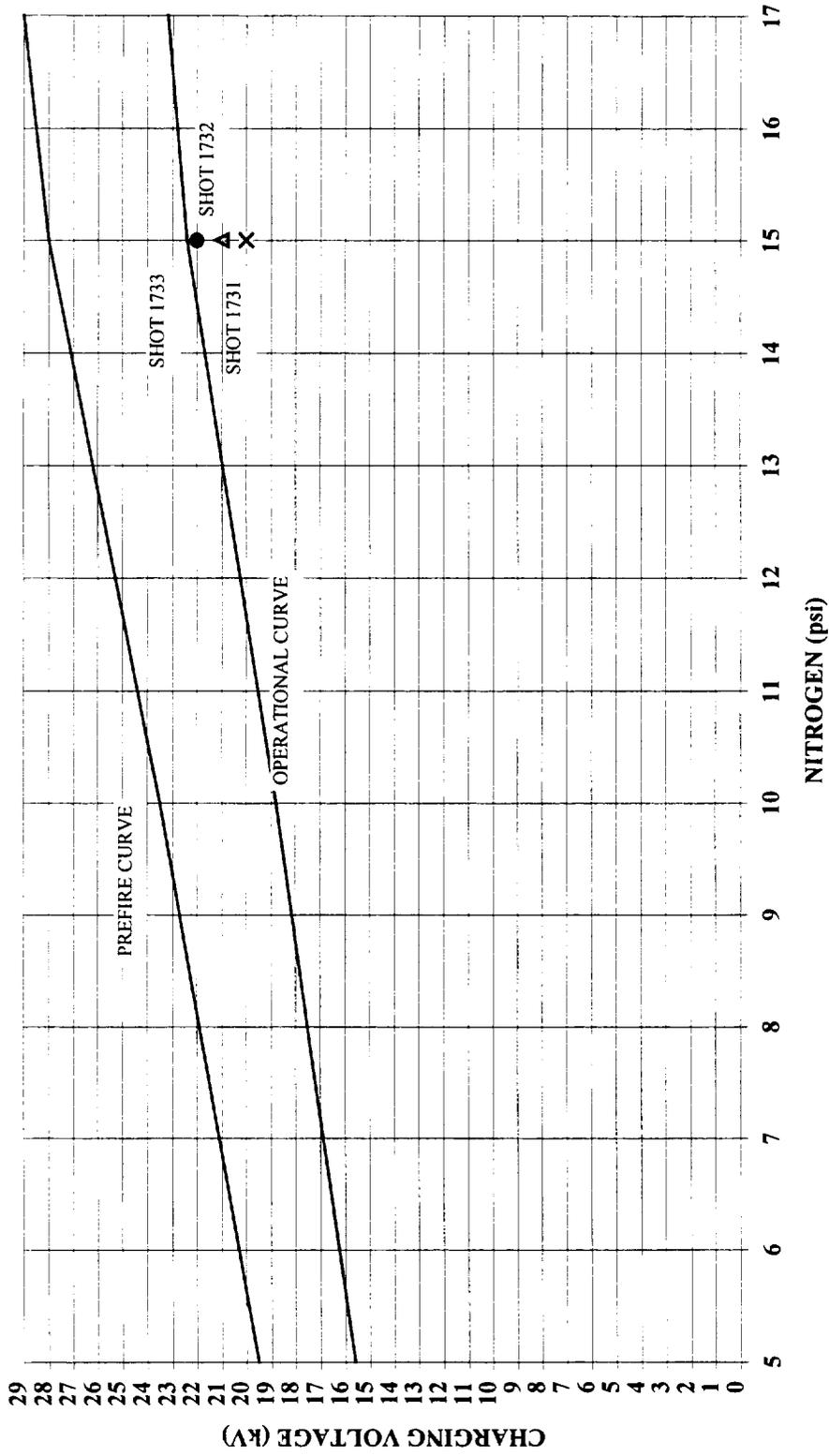


Figure 7. Shots 1731, 1732, and 1733 as compared to the operational curve for tube #3.

For proper operation of the flash x-ray system in the future, certain parameters must be maintained. These parameters include periodically replacing the fluorescing sheets and making sure the x-ray film is not too old and has been stored properly. In the systems present condition, proper operating parameters, from the operational curves, are at 17 kV and 8 psi, 20 kV and 12 psi, or 22.5 kV and 15 psi. These are all good operating parameters for the three tubes in their present condition. But operational curves need to be performed periodically to the system due to normal aging of the tube heads.

### **X-Ray Imaging Applications for Hypervelocity Experiments**

Flash x-ray systems are used in a number of recent space related experiment activities to determine important characteristics of materials at high velocities. The addition of a second x-ray system would greatly enhance MSFC's capabilities. Since we are not able to actually perform the precise experiment in space, simulated collisions of space debris with spacecraft materials are very important in designing for structures such as the Space Station and various other space vehicles. For example, a major difficulty in the planning process for Space Station is the use of a shield to protect the structure from a direct collision with debris. Current ground based hypervelocity facilities are limited in their ability to go above 7.5 km/sec. To estimate damage rates above that velocity, surrogate materials such as cadmium and zinc are being used.<sup>2</sup> Flash radiographs of the debris cloud spreading out from the collision of cadmium spheres with cadmium sheets allow visual measure of the same phenomena as aluminum spheres hitting an aluminum sheet. This approach provides a useful velocity scaling approach to designing shield for use in space.

Similarly the design of various configurations for a Whipple shield at MSFC have used the measurements from flash x-ray imaging to gather collision parameters at both MSFC and JSC.<sup>3,5</sup> These studies have also included metal matrix composite structures such as various alloys of aluminum with SiC particles and Al-graphite epoxy fibers. Since the composite bumpers did not perform any better than aluminum alloys currently being used

for Space Station use, it is more cost-effective to stick with aluminum alloys for the shield applications.

Work above 10km/sec has been performed by researchers from Southwest Research Institute.<sup>6</sup> Comparisons of experimental results using shaped charges of aluminum of L/D from 2.92 to 1.32 and molybdenum and nickel, impacting on 6061 Al, the researchers were able to extend the database into projectiles consisting of elements considerably harder than aluminum. Since comparing the actual dynamics of collisions between metallic spheres and sheets is important for developing a solid theoretical basis, the x-ray imaging capability is the only method for truly imaging into the material flow on impact. In addition to bulk materials, work with polyurethane structures was studied by Trucano and Grady at Sandia Labs.<sup>7</sup> The low density targets represent the simulated impact of micrometeoroids into a planetary body. X-ray imaging provided a useful visualization for modeling purposes.

Of particular interest is the work of A.J. Piekutowski<sup>4,8-9</sup>, which encompasses several applications from spacecraft shields to experiments used to obtain a better understanding of the collision process itself and the resulting debris cloud. More recent work with tungsten alloy long rods provided valuable information for modeling on penetration into high-hard steel targets.<sup>10</sup> The measurements of the time and position parameters during impact was accomplished using x-ray imaging approaches. More work with ceramic laminated targets<sup>11</sup> was performed collaboratively with emphasis on scale model experiments. An extended review on impact loading of plates and shells by free flying projectiles was developed by Corbett and his collaborators in Europe<sup>12</sup>. Experimental parameters using x-ray imaging for parameterization and modeling provide a large foundation in their work. More work with ceramics was reported by Orphal, et. al.<sup>13</sup> in their work with aluminum nitride targets using tungsten long rod projectiles. This work relates to armor protection and the use of x-ray imaging to acquire impact parameters provides a good experimental basis for validation of current theoretical concepts.

## CONCLUSIONS

The use of x-ray imaging systems for acquiring real time information of events during hypervelocity impacts has been shown to be a necessary instrumentation implementation for practical consideration of current problems in space shielding and armor protection. The proper use of the x-ray imaging capability requires a careful consideration of the parameters used in setting up the system. Fast and repeatable responses are necessary for this work, making the set-up of the instrumentation a careful procedural set of events. Once ideal parameters are identified, the system has been shown to provide repeatable measurements from shot to shot.

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