UM-HSRI-76-3

WHOLE BODY RESPONSE

RESEARCH PROGRAM

SECOND YEAR FINAL REPORT

(September 1, 1974 - August 31, 1975)

by

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16. Abstract

The general objectives of the program are to obtain data on human whole body kinematics under controlled test conditions which represent realistic automotive impact environments. The test subjects in the program are unembalmed male human cadavers which are suitably instrumented and subjected to the test environments at various levels of crash severity. Prior to testing, anthropometric measurements, including x-ray anthropometry, are made on each subject to quantify the subject's geometric characteristics and to locate the test instrumentation with respect to anatomical landmarks. The results of the test program are being analyzed to provide information for the development of scaling laws for percentile rating of response data and for prescribing performance requirements for dummy response evaluation.

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1.0 INTRODUCTION

The Whole Body Response research program, conducted by the Highway Safety Research Institute (HSRI) of the University of Michigan, and sponsored by the General Motors Research Laboratories, is now in its third year.

The objectives of the program are to generate data on the kinematic response of the human body, restrained by a 3-point belt system, and subjected to realistic automotive impact environment. The test conditions and test subjects (unembalmed male human cadavers approximating the 50th percentile in size) are suitably documented and instrumented, so that all the information necessary to analyze and evaluate the data is recorded. The data generated by these tests are to be utilized for the development of humanlike response requirements for anthropomorphic dummies and mathematical models.

Much of the first year of the program was spent in initial development. This included designing instrumentation hardware, and developing data processing techniques. This work resulted in improvement of the sophisticated measurement techniques and data analysis capabilities necessary for providing the quality of data required for effective performance of the program.

During the second contract year, the surgical techniques were refined, the instrumentation hardware was redesigned and improved to per-

* The protocol for the use of cadavers in this study was reviewed and approved by the Committee to Review Grants for Clinical Research and Investigation Involving Human Beings of the University of Michigan Medical Center and follows guidelines established by the U.S. Public Health Service and recommended by the National Academy of Sciences/National Research Council.

mit the use of Endevco Type 2265-2000 accelerometers, nine accelerometers (three triaxial clusters) were mounted instead of the original six accelerometer system, the photographic coverage was improved, and generally, the lessons from the first year resulted in the refinement of the test protocol.

A total of twenty-five sled tests were conducted during the second year period. Four cadavers were each subjected to two tests, and a certified Part 572 dummy with two types of instrumentation was subjected to seventeen tests of three severity levels for the purposes of comparison with cadaver response and to compare instrumentation differences.

This presentation is the Final Report (2nd year) covering the period of September 1, 1974 through August 31, 1975. This report discusses the details and revisions of the test procedures and presents all the raw data collected in the second contract year.

2.0 DESIGN OF EXPERIMENTS

The Whole Body Response program requires an accurate, detailed description of both test subject and test conditions as well as the recording of the data necessary to analytically describe the kinematics during impact. This section discusses the details and techniques utilized to obtain this data.

2.1 Test Subject Description

The test subject's physical description is obtained by means of detailed anthropometry measurements taken before surgery for transducer installation is begun. The Anthropometry data sheet listing the measurements that are recorded appears in Appendix A with the cadaver data presentation. Diagrams are being prepared to illustrate and clarify the terminology.

In addition, a complete x-ray record is made of the skeletal structure in both a lateral seated view that simulates the test configuration and a prone frontal view after surgery has been completed. Biplanar orthogonal x-rays of the head allow the spatial relationship of the headset accelerometers to the physiological axes of the head to be determined mathematically. The theoretical basis of this technique is presented in Appendix C. The measurements that must be made at the time of the x-rays to permit this relationship to be calculated appear on the x-ray data sheets in Appendix A.

2.2 Test Conditions

The test environment at the onset of impact is described in terms of the test subject's configuration and restraints. The positioning and targeting diagram provides the record of initial conditions, and the belt length data form give a detailed geometry of the three point restraint system. These forms are used for data presentation as well as test setup and appear in Appendix A.

The subject is seated for a frontal impact in G.M. supplied test fixture and is restrained by a three point belt system instrumented with load transducers in a driver's side configuration. The foot rests are adjusted to provide the leg angles specified in the targeting and positioning diagram. All the belts are tensioned to a ten pound preload and then three inches of slack is introduced into the shoulder belt. Two impact tests are conducted on each subject, with the lower severity impact first to minimize any effects from skeletal damage. Three levels of impact severity are used in this program; they are as follows:

High-severity

33 mph velocity change

20 g constant deceleration

(equivalent to 21.8 in. stopping distance)

Intermediate-severity

23.3 mph velocity change

10 g constant deceleration

(equivalent to 21.8 in. stopping distance)

(half the kinetic energy of the hi-severity)

Low-severity

16.5 mph velocity change

10 g constant deceleration

(equivalent to 10.9 in. stopping distance)

(half the kinetic energy of the intermediate severity test)

2.3 Cinematographic Coverage

To describe the three dimensional kinematics of the test subject during impact, cinematographic data is obtained for the photo targets installed on the skeletal structure of the subject. As discussed in Section 4 , the photo targets are spherical for all positions except on the femur so the same point in space can be identified and tracked from any camera position. These spherical targets are used at the following positions:

a. Head - a spherical shell encloses and targets the effective inertial center of each of the three accelerometer triaxial packages.

b. Thorax - a spherical target is attached to the triaxial accelerometer mount measuring the acceleration at the T_8 level.

c. Pelvis - two spherical target assemblies are attached to the biaxial mounting fixture for photometric analysis of pelvic motion during impact.

d. Acromion(shoulder) - a spherical target is attached to the acromion on both right and left sides.

Photographic coverage consists of four high speed movie cameras operating at nominally 1000 frames per second. Color film is used and a ten millisecond timing light pulse is imposed at each camera to accurately calibrate film speed. A single strobe flash at the onset of impact allows synchronization of all cinematographic and magnetic tape data. The cameras are situated to provide four orthogonal views of the impact - right side, left side, overhead and frontal. In addition, a Polaroid graph-check camera provides an immediate eight sequential exposure review of the test.

2.4 Instrumentation

Accelerometers are surgically attached to the test subject's skeletal structure to provide the following data during impact.

1. Head - three triaxial accelerometer headset from which three-dimensional head motion is to be obtained.

2. Thorax - AP, SI, LR accelerations at the T_8 level measured by accelerometers fastened to the spinous process of T_7.

3. Pelvis - AP, SI accelerations.

Belt load cells are installed in the restraint systems and used to determine the belt webbing forces acting on the subject during the test.

The sled deceleration, sled velocity, t_0 strobe pulse, and ten milli-second time base pulses are also recorded. Light beam oscillograph records from the original tape are made. M1650 galvos are used on all channels except for an M100 galvo on the sled deceleration channel.

2.5 Data Analysis

In general, the cinematographic data is analyzed in the following manner:

1. Analyze films using the Vanguard Motion Analyzer.
2. Compute film speed.
3. Synchronize film time base to tape time base by recording frame number for strobe flash.
4. Geometric scale factor determination -- Measure length of scale factor target on sled. Use in conjunction with camera-to-occupant target distances to compute geometric scale factors.
5. Measure X, Y, and θ as a function of frame number for every 1000 Hz timing mark and a frame approximately midway between marks.
6. Analyze data by computer to obtain the following data as a function of time.

   a. Head cg displacement from initial position (X,Y,θ).
   b. Head cg displacement relative to thorax (X,Y,θ).
   c. Thorax displacement from initial position (X,Y,θ).
   d. Pelvis displacement from initial position (X,Y,θ)
   e. Pelvis/thorax angle change.
   f. Femur/pelvis angle change.
   g. Shoulder displacement relative to thorax (overhead).
7. Differentiate the above quantities once to obtain velocities.
8. Use computer graphics package to plot output.

Likewise, the instrumentation data stored on magnetic tape is processed as follows:

1. A-to-D conversion of all acceleration and force data. Digitized data will be stored on magnetic tape, and store original analog tape.
2. Light beam oscillograph records from the original analog tape will be made. M1650 galvos will be used on all channels, except for an M100 galvo on the sled deceleration channel.
3. Apply MVSS 208 filtering to head and chest acceleration data.
4. Apply MVSS 208 filtering to pelvis acceleration and belt force data.
5. Compute three dimensional head motions versus time using filtered data.
6. Compute head and chest resultant accelerations versus time using filtered data.
7. Compute Gadd Severity Index (GSI) and head injury criterion (HIC) for the head and chest, using filtered data, as follows:
   a. Head -- GSI and HIC for AP, SI, and LR components, and for the resultant.
   b. Chest -- GSI versus time for the AP, SI, and LR components, and for the resultant.
8. Use computer graphics package to plot output.

3.0 PROGRAM STATUS

3.1 Background

Whole body response studies sponsored by GMR commenced at HSRI July 1, 1973 for one year with a funding of $62,705. A no-cost extension carried the program to August 31, 1974. A one-year renewal was negotiated to carry the program from September 1, 1974 through August 31, 1975 at an additional cost of $60,000. The research originally planned in this program is summarized below.

1. Three-point belts restrained response evaluation from 20 tests on 10 unembalmed cadaver subjects and 18 tests on a Hybrid II dummy subject.

2. Chest/shoulder system response evaluation from 13 tests on six unembalmed cadaver subjects and 18 tests on a Hybrid II dummy subject.

3. Preinflated air cushion restrained response evaluation from 13 tests on six unembalmed cadaver subjects and 18 tests on a Hybrid II dummy subject.

3.2 Testing Schedule

The above research program has progressed at a much slower rate than anticipated. Significant problems leading to this situation include:

1. Underestimation of the complexity of the experimental/analytical three-dimensional head kinematics analysis.

2. An unanticipated problem in procuring the cadaver subjects during the summer of 1974.

3. Unanticipated problems with accelerometer instrumentation, and delays in procuring replacement equipment.

As of August 31, 1975, twelve cadaver tests using six cadavers and seventeen certified dummy tests had been completed using the three point belt restraint system. No work on the chest/shoulder system or pre-inflated air cushion experiments will be pursued in the present program. The present state of instrumentation, surgical techniques and related equipment now permits the Whole Body Response cadaver tests to be performed on a relatively routine basis whenever a cadaver becomes available. The supply of suitable 50th percentile unembalmed male cadavers remains as the sole obstacle to completing the required number of tests.

3.3 Rib Damage Problem

A significant, unanticipated result consistently being observed in the three-point belt restrained experiment is that unembalmed cadaver subjects are sustaining considerable damage in the thoracic region. Damage has included rib, sternum, and clavicle fractures. Cervical spine dislocations have also occurred.

Initially, the two tests on a cadaver subject consisted of an intermediate severity run followed by a high severity run, and it was thought that the high severity condition caused the damage. Later experimentation illustrated, however, that significant damage could be induced by two intermediate severity tests. There is some evidence that the first test leads to significant structural degradation of the subject, leading to fractures during the second test.

Significant thorax and cervical spine damage has a non-negligible effect on the kinematics of the subject. Accordingly, this is an unacceptable situation for a biomechanical response evaluation. Therefore, a third, low severity impact condition as defined in Section 2.2 was introduced for WBR#6, the last cadaver test of this report and for the certified dummy tests. Hopefully, two impact tests on a cadaver -- low severity followed by another low severity or an intermediate severity -- will not produce signficant skeletal damage while yielding useful kinematic data.

3.4 Accelerometer Mounts

It is felt that the present design of accelerometer mounts provides satisfactory attachment to the cadaver's skeletal structure and only minor detail improvements are anticipated. The thoracic mount remains the most fragile and is also most likely to be damaged during rebound by fracture of the spinal process, but careful positioning of the seat back support bolsters and a reduction in sled rebound braking deceleration have greatly reduced the incidence of breakage. The new head accelerometer mounts have proven to be quite strong and have taken severe blows against the seatback during rebound without harm. However, foam padding has been added to the seatback in the area of head impact to reduce the shock to the accelerometers.

4.0 PROGRAM REVISIONS

This section discusses the changes that have been made to the program during the second contract year. Most of the revisions were a result of changing from Entran to Endevco accelerometers to improve reliability, packaging and signal quality. As new mounts were designed to accomodate the Endevco accelerometers, changes were also incorporated in the mounting techniques to eliminate problems encountered in earlier testing.

4.1 Experimental Procedure Revisions

4.1.1 Pulmonary Pressurization

As of WBR-4, lung pressurization was introduced to determine the effect of inflated lungs on the rib breakage problem discussed in Section 3.2. The procedure involves inserting a plastic tube into the trachea during surgery and clamping it closed until the test. Immediately before testing, the lungs are inflated with a regulated air supply adjusted to 5 mm of mercury, and then connected to a pressurized reservoir fixed to the sled to maintain the inflated state during the test.

4.1.2 Head Accelerometer Installation

A new design accelerometer headset replaced the original welded magnesium tube fixture used through WBR-2. The head is shaved as before to facilitate surgery. Three locations are selected on the skull for accelerometer mounting, a one inch diameter section of scalp removed at each location and a 3/8 inch diameter hole drilled through the skull outer table at each site. The holes are enlarged to an oval shape just sufficient to allow insertion of the machined rectangular bolt heads and the soft diploë layer between tables is removed to permit the bolts to be rotated and locked between tables. The three bolts are potted in this position with dental acrylic, a flat washer put over each bolt to provide a level surface, loctite put on the bolt threads, and the potting cups screwed onto the bolts and tightened securely. The accelerometer mounting blocks are attached to the installation fixture, and the fixture is adjusted to position each of the mounting blocks into a potting cup. The fixture is removed, the cups filled with dental acrylic and the fixture reinstalled. The positions of the mounting blocks along the fixture axes are measured and recorded (see Figure 1) and the fixture is unbolted and removed when the acrylic is set, leaving the accelerometer mounting blocks potted into the cups in a known configuration.

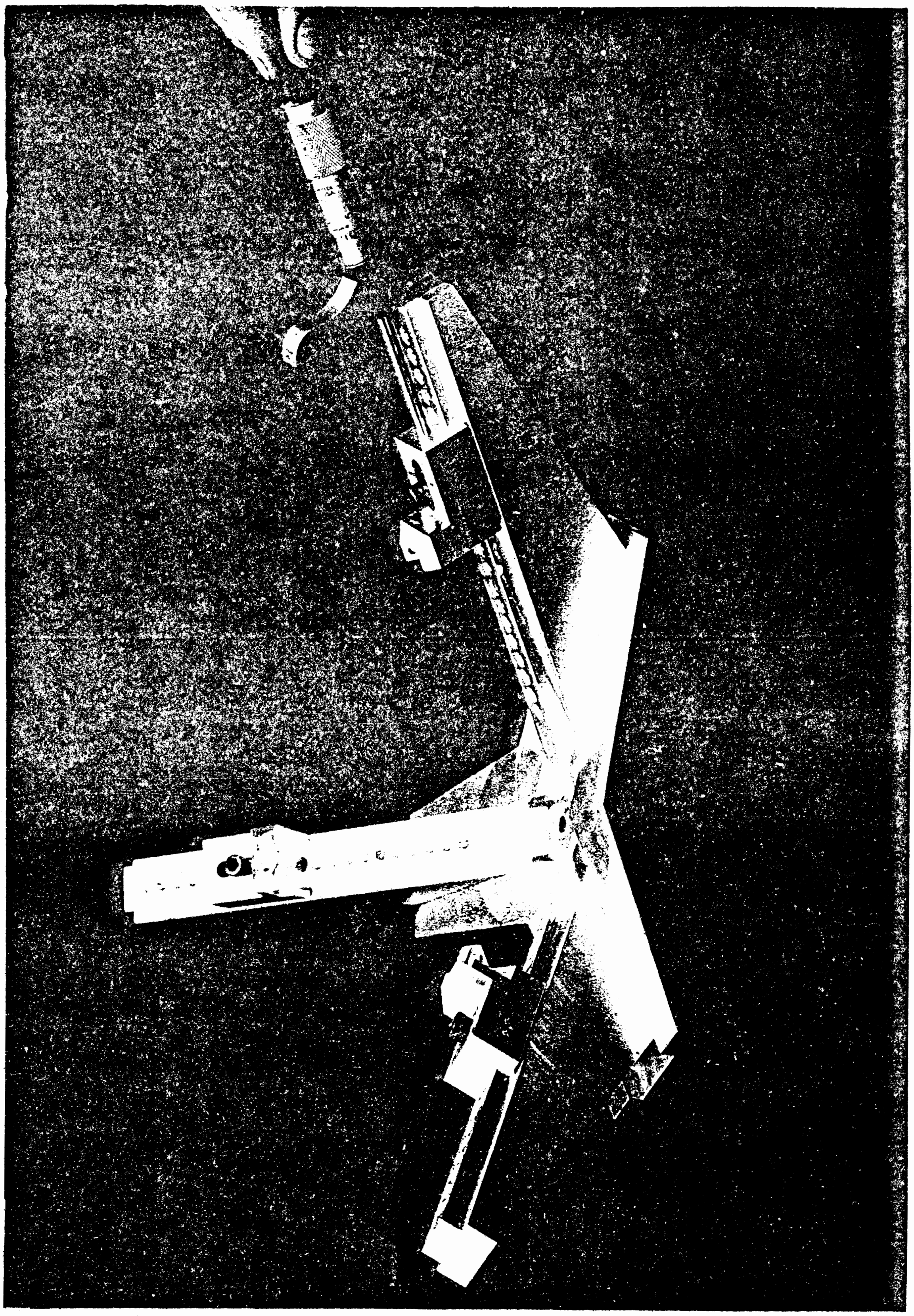


FIGURE 1: MEASUREMENT OF AXIS ON HEADSET INSTALLATION FIXTURE

4.1.3 Thoracic Accelerometer Installation

A lighter, more compact thoracic accelerometer fixture was designed to accomodate the Endevco 2264-2000 accelerometers in a triaxial configuration. (See Figure 2). The basic principle of potting a tube to the spinal process of T_7 with dental acrylic was retained, with the addition of the process being drilled along its axis and a sheet metal screw threaded in part way to strengthen the process and improve retention to the potting compound.

4.1.4 Pelvic Accelerometer Installation

The pelvic accelerometer mount was also lightened and redesigned to accomodate the Endevco 2264-2000 accelerometers in a biaxial configuration (See Figure 3). To attach the new pelvic mount, two incisions were made down to the posterior, superior pelvic crests, a hole drilled in each crest in the A-P direction, and a coarse lag bolt threaded in until flush with the skin. (See Figure 4). The lag bolt heads are predrilled and tapped for attaching the aluminum channel to which the two Endevco accelerometers mount.

4.1.5 X-Rays

Difficulties remain in obtaining good skeletal definition in the lateral seated x-rays. The tendency of the cadavers to be osteoporotic and edemic are the primary reasons for this problem. It was found that the plastic sweat suits were causing additional x-ray scatter and they are now fitted to the cadaver after x-rays are completed.

The lead pellets used to locate the effective inertial center of the headset triax units on the head x-rays are sometimes difficult to identify on the two orthogonal exposures.

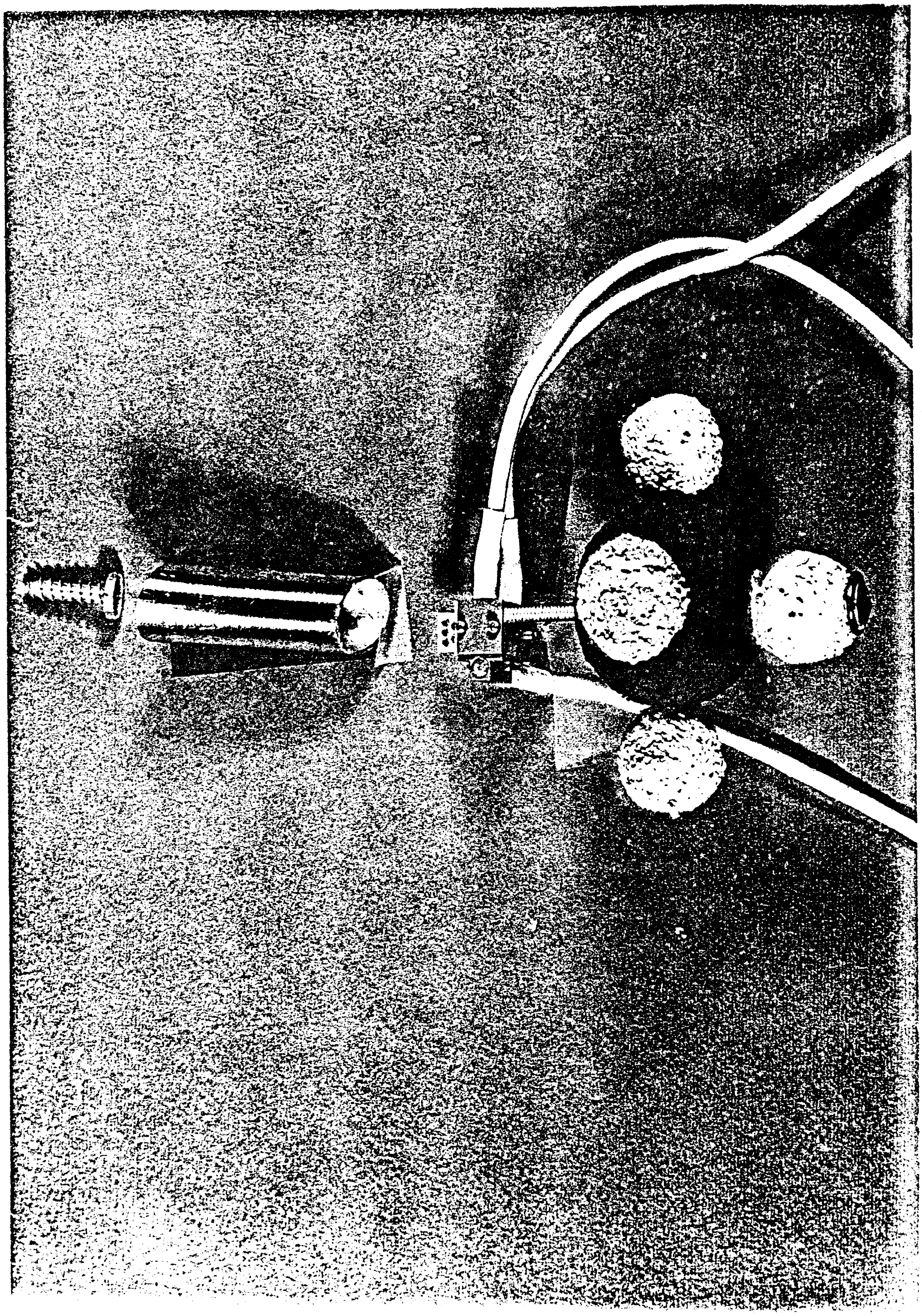


FIGURE 2: THORACIC ACCELEROMETER FIXTURE

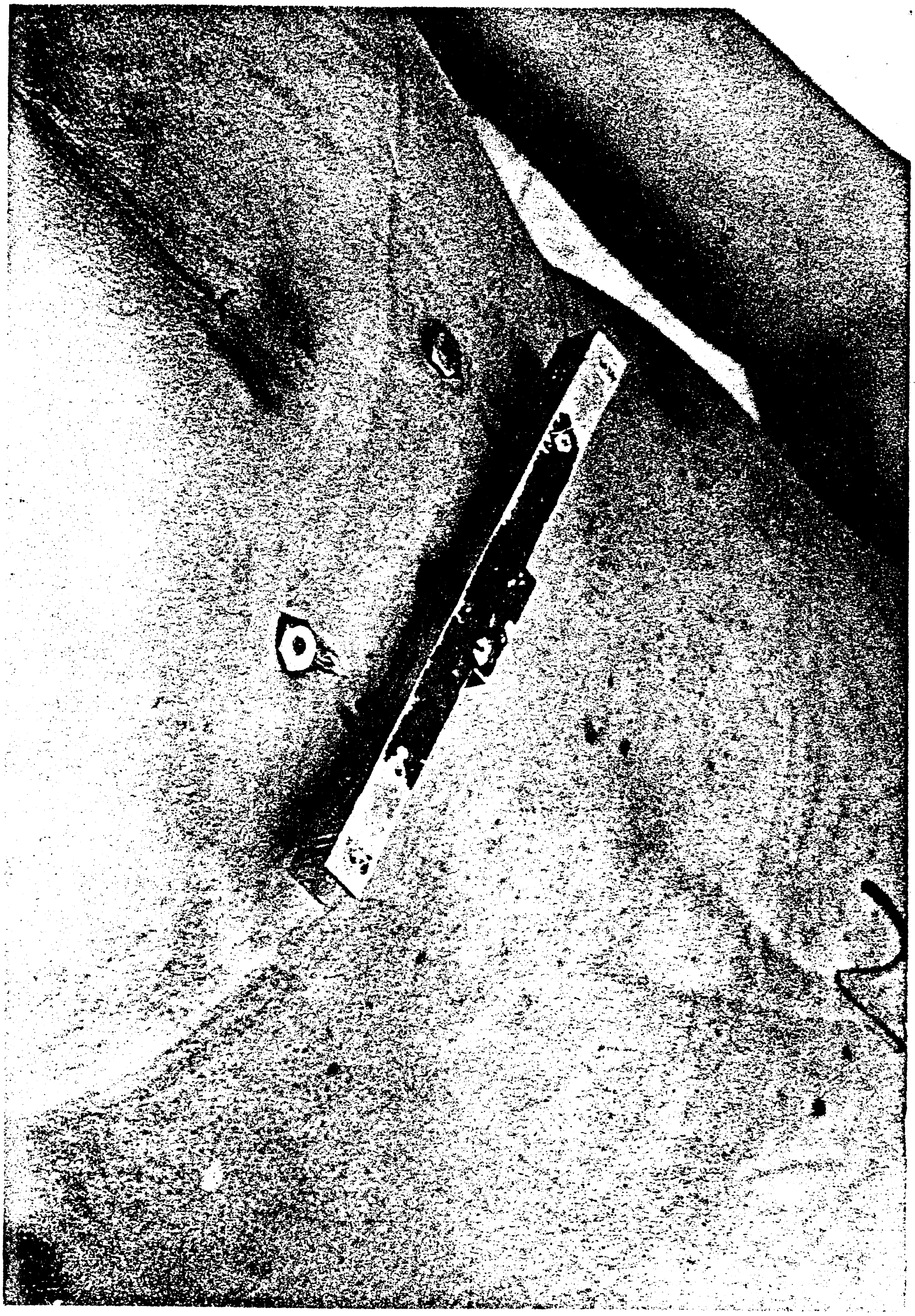


FIGURE 3: PELVIC ACCELEROMETER FIXTURE

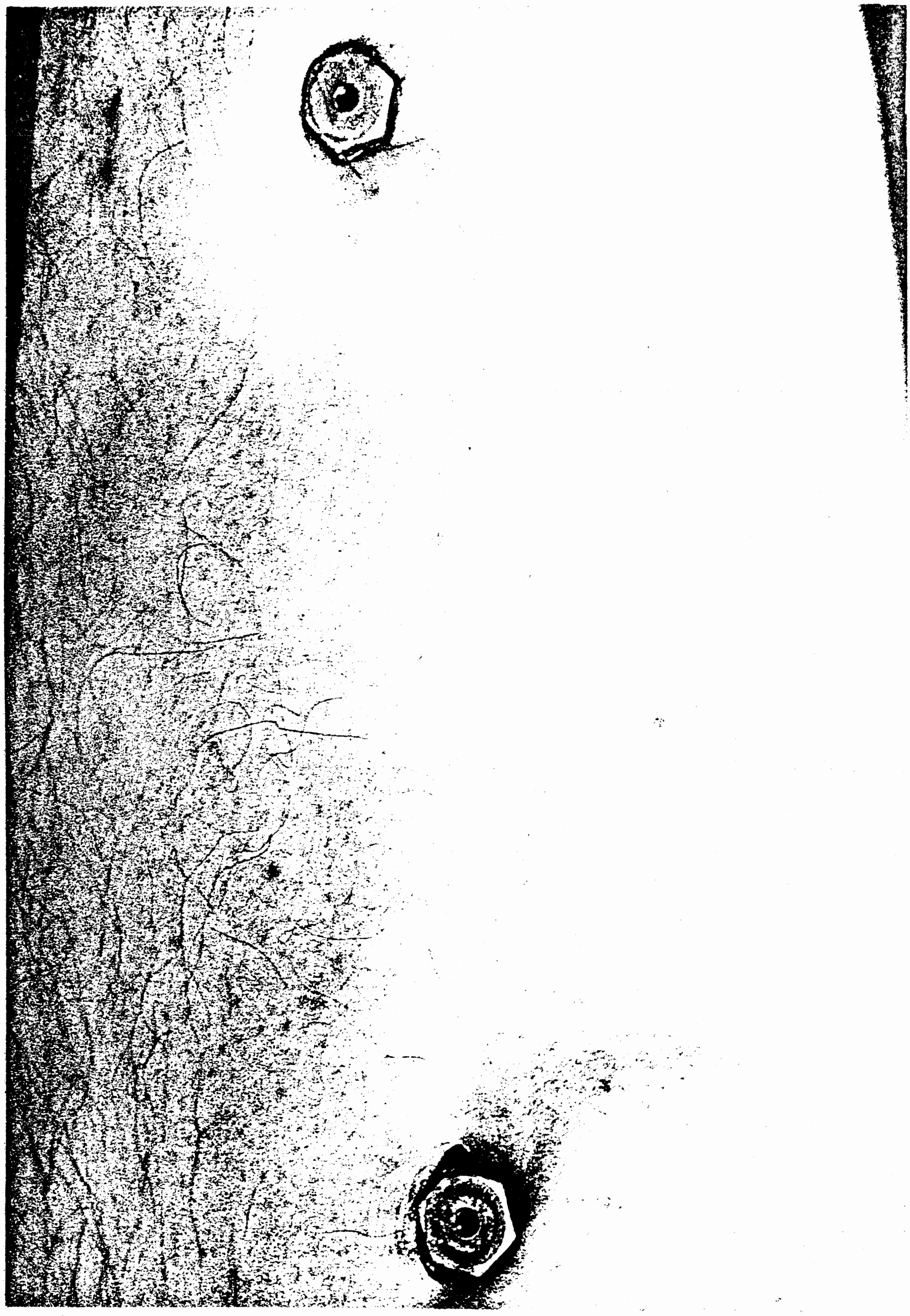


FIGURE 4: PELVIC LAG BOLT INSTALLATION

Lead numbers 1, 2, and 3 are now being attached before taking x-rays to correspond with the Q_1, Q_2, Q_3 accelerometer positions and permit much more reliable analysis of the head x-rays.

4.1.6 Discussion of X-Ray Grids

X-ray filter grids improve the contrast quality of radiographic images by trapping the greater part of scattered radiation. Scattered radiation is the largest single factor responsible for poor radiographic image quality, assuming other exposure factors are appropriate, and is always present. Its effect is to produce a general photographic fog on film which reduces contrast between adjacent areas. Amount of scattered radiation depends on subject density, total volume irradiated, and intensity of the primary x-ray beam. The only known way to remove effectively the greater part of scattered radiation is by use of an x-ray filter grid, since radiation which does not travel in the same direction as the primary beam is absorbed by lead strips of the grid.

X-ray grids are commercially available with either focused or parallel lead strips. These two types are produced in either linear or crossed-grid configuration. The focused grid has its lead strips angled progressively in such a way that lines through the grid and continued out from the grid will intersect at a specified distance from the grid. This distance is called the focal distance of the grid. The crossed grid is usually two linear grids, one on top of the other, so that the lead strips cross each other. The crossed grid will remove more scattered radiation than a linear grid. Focused grids may be used satisfactorily through a small range of distance called the focal range. Grids are characterized by the so-called grid ratio, which is simply the ratio of the height of the lead strips to the distance between them. Distance between strips is generally 0.010-in., so if strip height is 0.080-in., then the grid ratio is 8:1. A strip of height 0.120-in. would give a 12:1 grid, and so on.

Exposure factors for many of the earlier lateral radiographs of cadavers were set for a 12:1 linear grid with focal range suitable for 52" distance. It was thought that the x-ray table contained a long focal length 12:1 linear grid, based on information obtained from Picker, and data accompanying the unit. When successive lateral radiographs showed substantially less than expected minimum results, the table assembly containing the grid was removed, and it was found that the x-ray table contained an 8:1 grid with a focal range of 34-in. to 44-in. Subsequently, lateral views improved, except for two specimens which were extremely large and edemic.

Installation of a 12:1 linear grid would significantly improve radiographic contrast, but a second 8:1 linear grid is available with which an 8:1 crossed grid experiment will be performed with a lateral lumbar spine view. It is expected that scatter removal will be roughly equivalent to a 16:1 linear grid, which would be considerably superior to a 12:1 grid ratio.

4.2 Impact Testing Revisions

The following changes have been made in the setup procedures for Whole Body Response impact testing:

4.2.1 Instrumentation Data Sheets

The instrumentation data sheets have been modified to facilitate experimental setup and to provide a better record of calibration data, gain settings and transducer polarities. A simplified version without internal set up data will be used for data presentation as seen in Appendices A and B.

4.2.2 Belt Anchor Measurements

The belt anchor geometry measurements taken for each test set up have been changed to reduce the potential error and to simplify the measuring techniques. The revised belt anchor data sheet which outlines the information that is now taken to define the belt anchor positioning and orientation is used for all tests after WBR-5 and appears in Appendix A with the data presentation.

4.2.3 Subject Positioning

To assist in correctly positioning the cadaver on the sled, the footrest fixture side frames have been slotted vertically and horizontally under the attaching bolts to simplify the process of adjusting the correct leg angles. The seatback support bolsters against which the cadaver rests have been made vertically adjustable to facilitate adjusting the torso posture and to minimize interaction with and damage of the thoracic and pelvic accelerometer targets. The practice of tying the knees together at the required thirteen inch spacing and the use of paper tape with a punched hole to give controlled breakage for head positioning is being continued. The paper tape method is also being used across the shoulders to help maintain the torso vertical whenever slumping is a problem.

4.2.4 Subject Targeting

Targeting methods have been changed to improve durability and visibility and to adapt to the new accelerometer mounts designed for use with the type 2264-2000 Endevco accelerometers. Whenever possible, a spherical target is used for the accuracy it provides in photometric analysis since the target's center is the same point in space from any camera position. All the spherical targets are constructed from pre-formed styrofoam balls for lightness and are painted with a bright poster paint. They are attached with 6-32 machine screws pushed through the center of the balls and bonded in place. This configuration is used on the thoracic mount (Fig. 5), the pelvic mount (Fig. 6), and for the acromion targets (Fig. 7). The pelvic and thoracic targets simply thread into tapped holes provided in the accelerometer mounts, the acromion target threads into the tapped head of a lag bolt which has been threaded into the bone. The femur targets, which are flat discs, also attach to lag bolts which are threaded into the femur (Figure 8).

The headset accelerometers are targeted with spherical shells cut from ping-pong balls. Each triax is enclosed in a shell of this type which has been machined so that when in position as shown in Figure 9 , the center of the sphere coincides with the effective center of the triax. The target shells are presently taped in place and painted

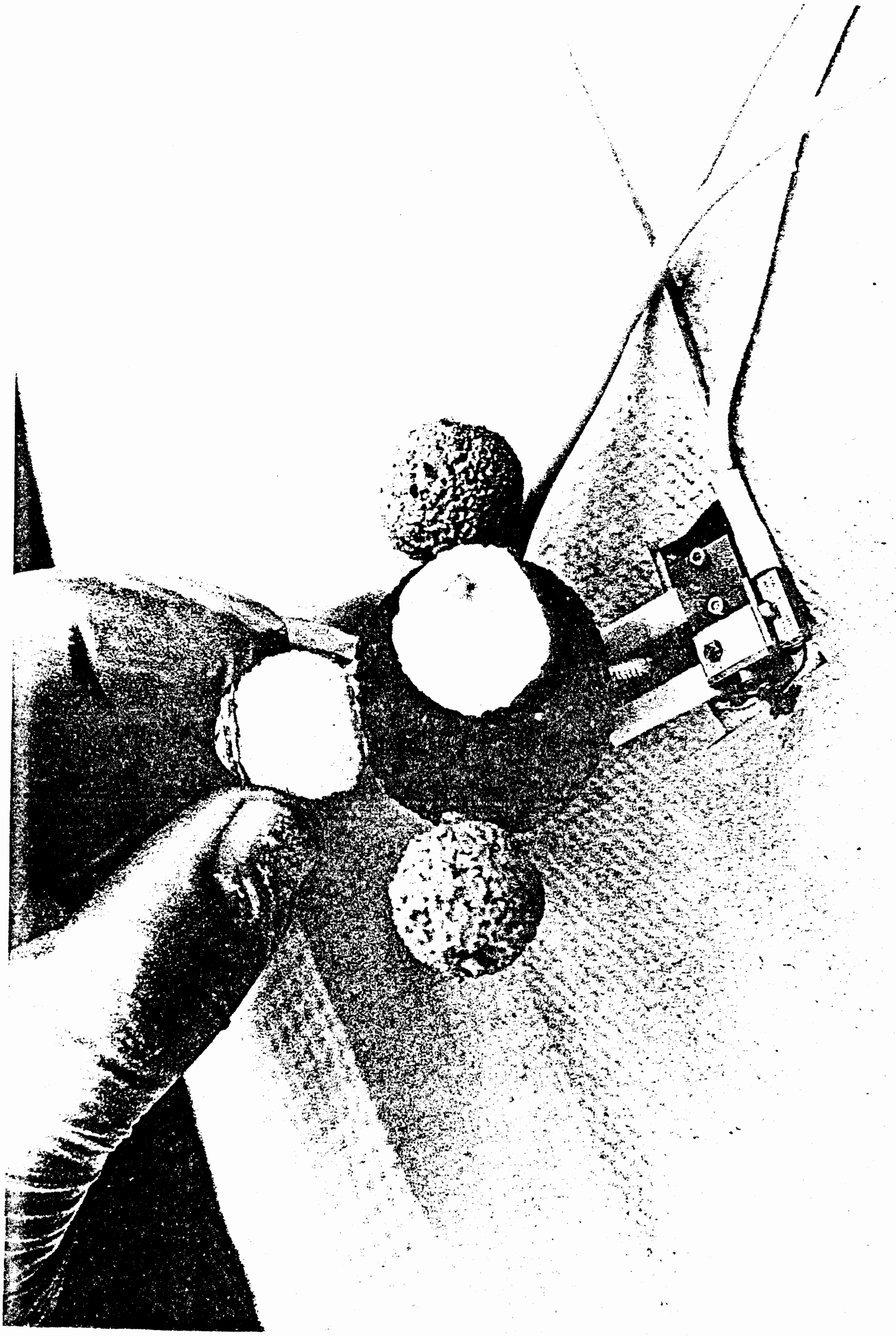


FIGURE 5: THORACIC TARGETING

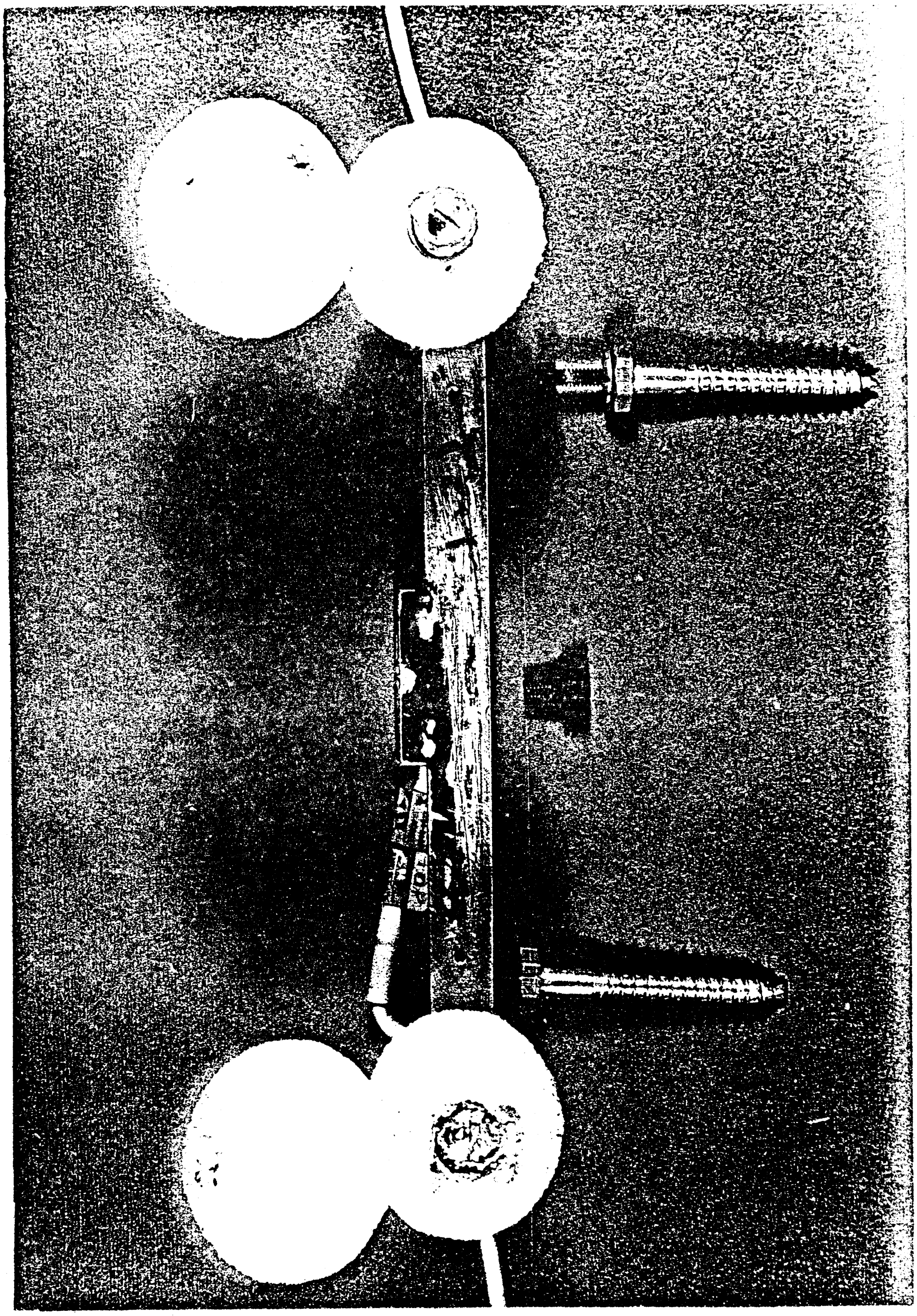


FIGURE 6: PELVIC TARGETING

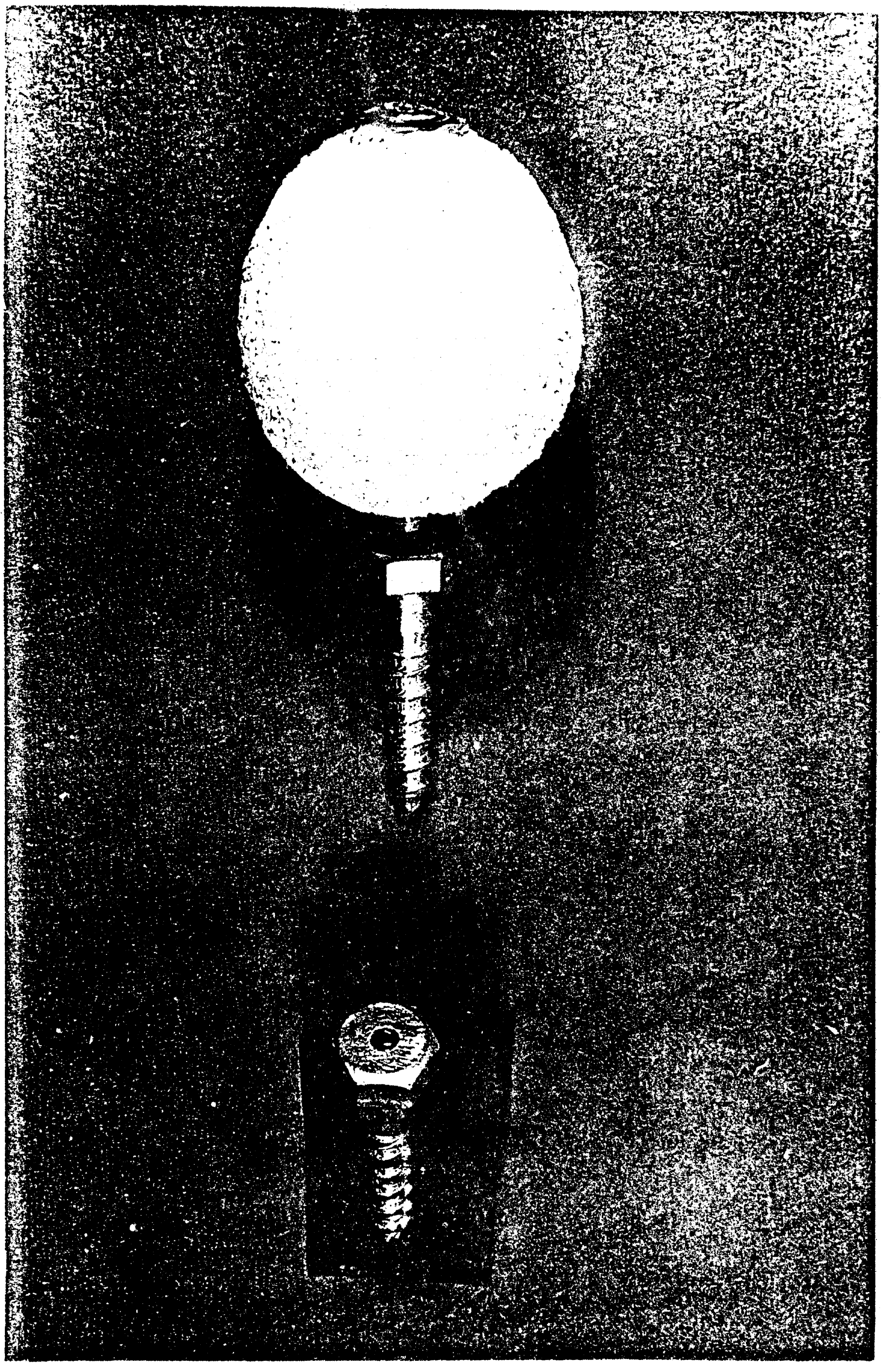


FIGURE 7: ACROMION TARGET COMPONENTS

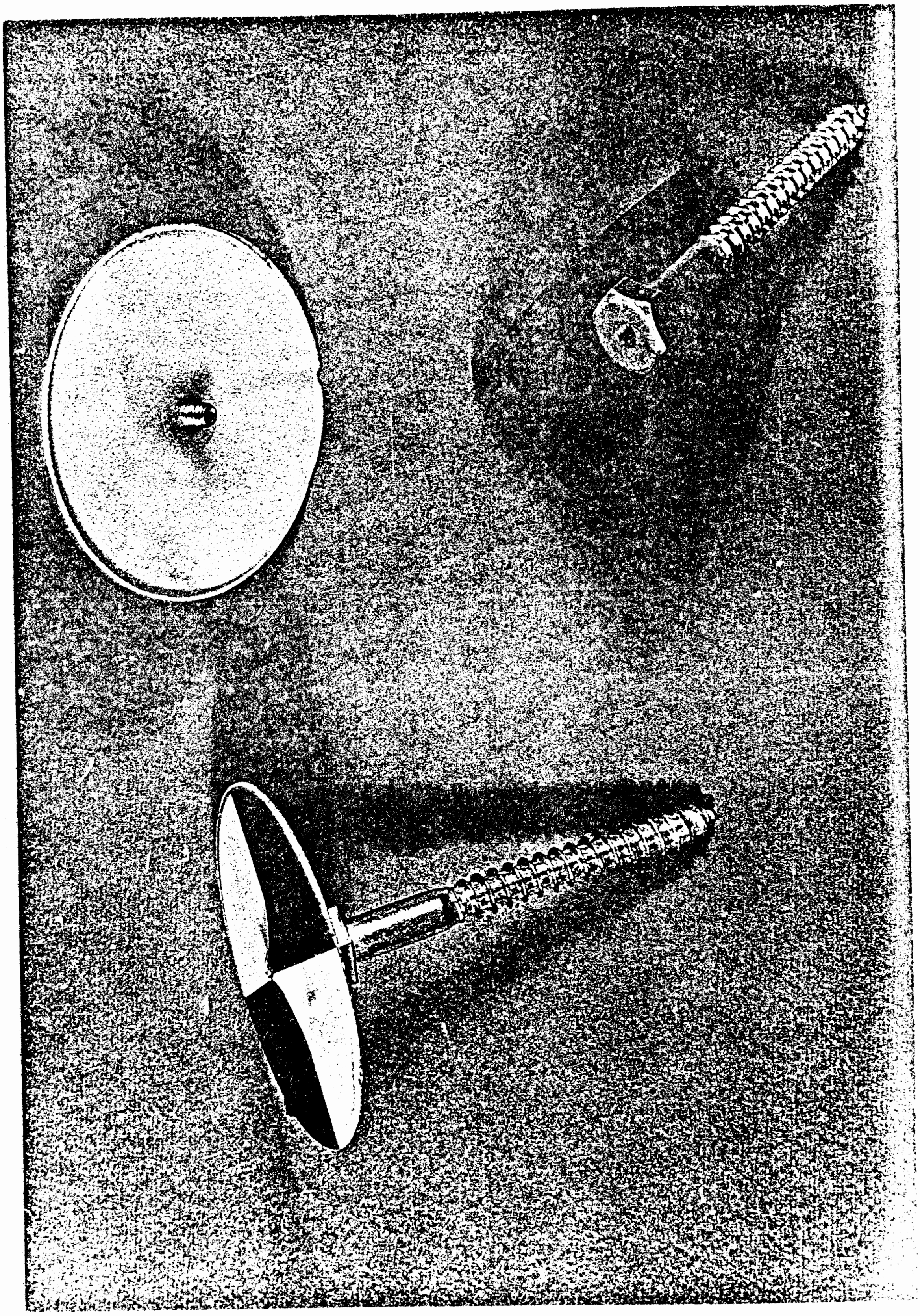


FIGURE 8: FEMUR TARGET COMPONENTS

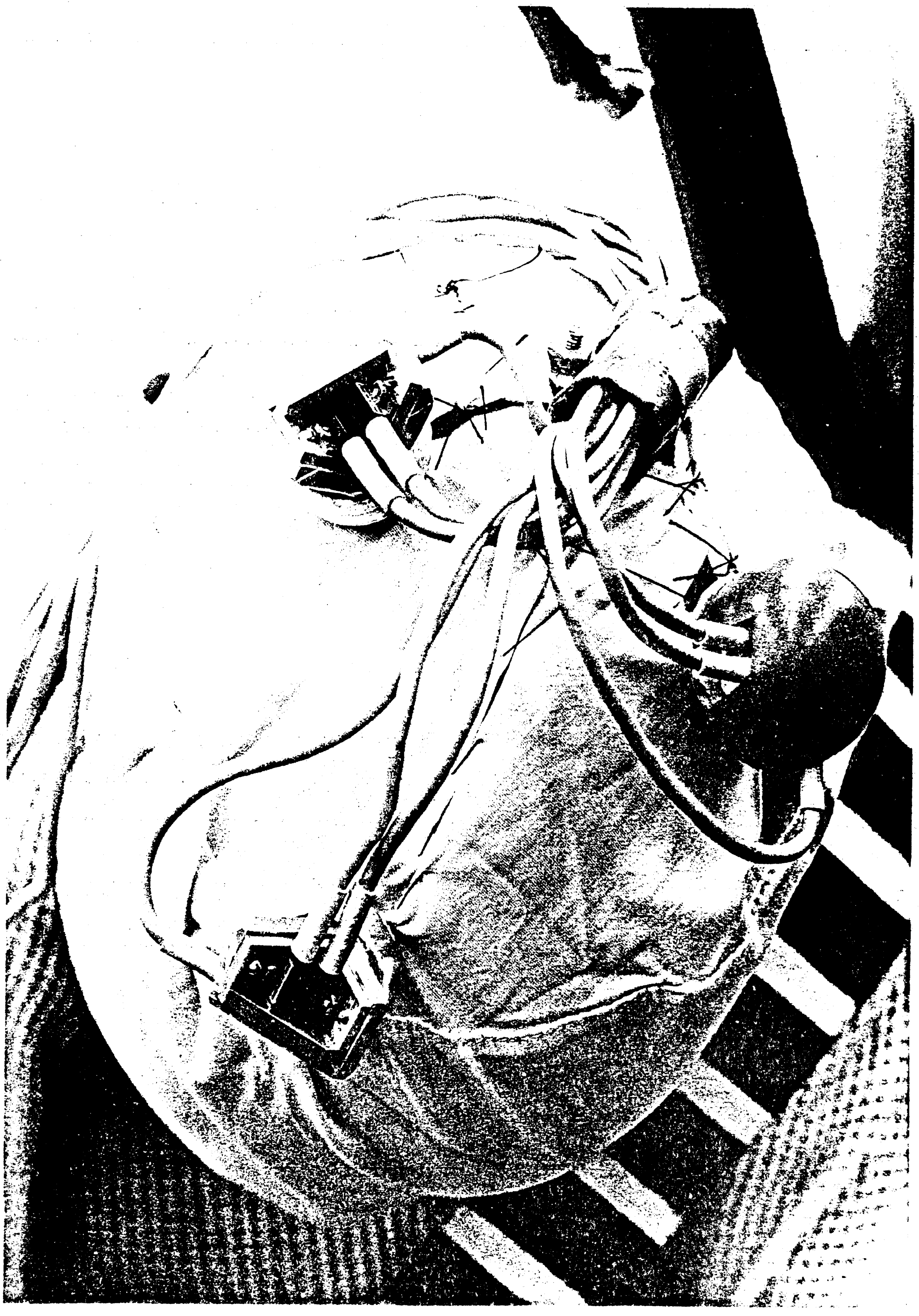


FIGURE 9: HEADSET ACCELEROMETER TARGETING

with a bright poster paint. Attachment with a small light weight machine screw will be a future improvement to simplify installation and to improve the appearance of the headset triax target.

The original method of using nylon wire wraps to strap femur target discs to the thigh proved unsatisfactory since the wire wraps tended to fail during impact. The present method utilizes two coarse lag bolts screwed directly into each femur at a separation of approximately twelve inches. A short incision is made at each target site and holes for the lag bolts drilled in the femur. The heads of the lag bolts are pre-drilled and tapped for attachment of the photo target discs. The femur target components are shown in Figure 8.

Spherical acromion targets were added as of WBR-4 and utilize the same method of attachment with the lag bolts as the femur targets. The photo targets are one inch diameter styrofoam balls rather than disc targets, and are coated with a bright poster paint. The acromion target components are shown in Figure 7.

4.2.5 Low-Severity Impact

As discussed in Section 3.3, a low severity impact was introduced as of WBR-6 because of the high incidence of rib fracture experienced in previous testing. Combinations of low and intermediate severity impacts will be conducted and the results evaluated to determine the test severity and sequence best suited for the study of dynamic whole body response.

5.0 SIGNAL PROCESSING AND DATA ANALYSIS

The complexity of experimental simulation of automobile impact situations has become so great, that an equally sophisticated system is required to handle and process the resulting data.

With the availability of digital computers, this task is greatly simplified. First analog signals are converted to digital signals which are then cleaned up and prepared for subsequent analysis and presentation. The cleaning process consists of truncating undesired portions of the signals, and filtering out frequencies, irrelevant to the anticipated analysis, using high-performance digital filters. The mathematical analyses are more complicated but, with digital computers, can be done with little or no effort. Finally, results are usually presented in graphical and/or tabular forms for easier interpretation and evaluation of the experiment.

The HSRI signal processing package, developed in the past year is only one phase of the total data handling system, which is diagrammed in Figure 10.

5.1. A-to-D Conversion

The first step in computerizing the data analysis is to convert all analog signals into digital form. The A-to-D process requires special care in selecting the sampling rate and/or the electronic filtering of the analog signals prior to digitizing. Details of the A-to-D system at HSRI are given in appendix E.

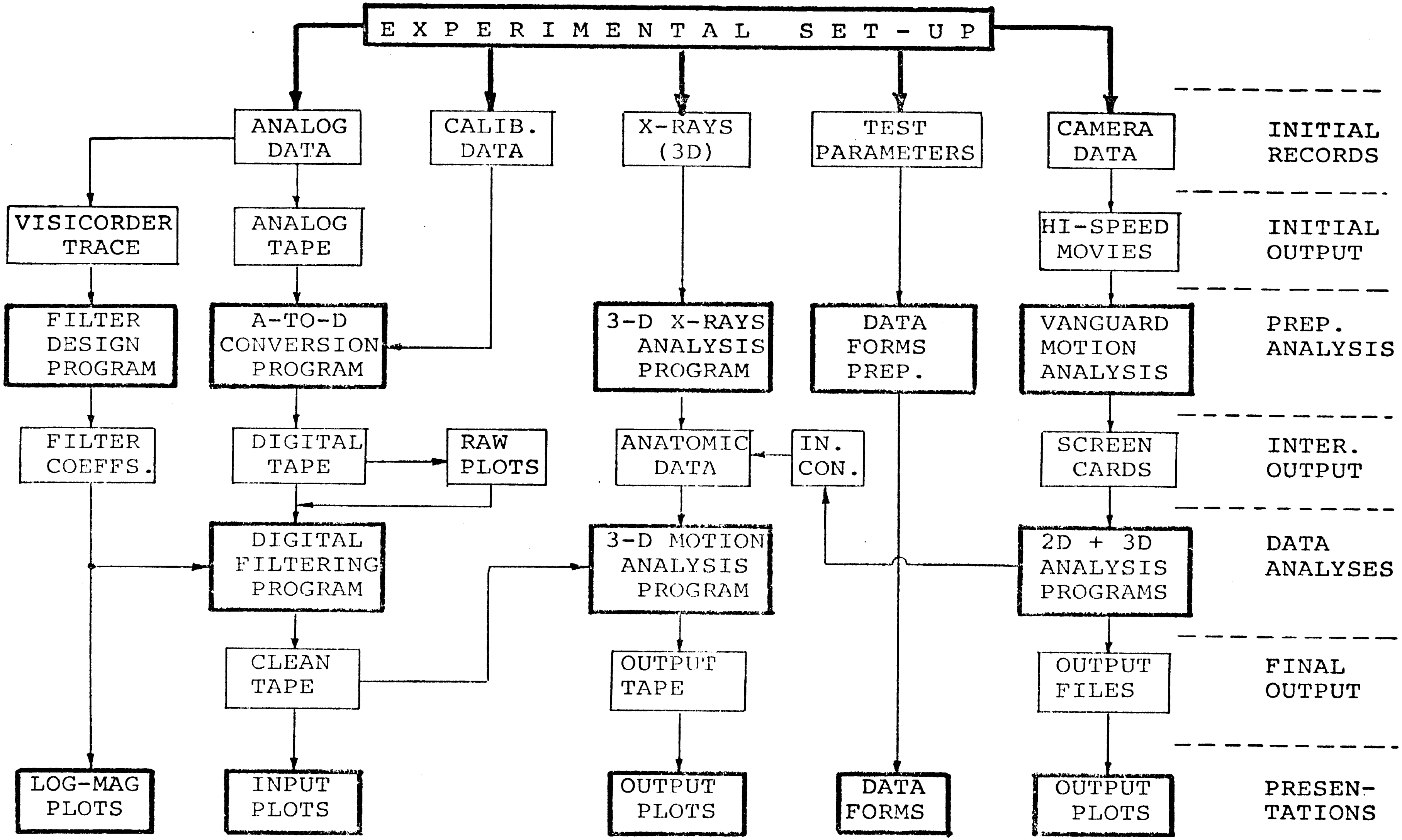


FIGURE 10. HSRI DATA HANDLING SYSTEM

5.2 Digital Filtering

The data measured and recorded during any given test in this project falls into one of the following categories:

		channel class
a.	sled deceleration (g's)	60
b.	restraint system loads (lbs)	60
c.	femur forces (lbs)	600
d.	chest accelerations (g's)	180
e.	pelvis accelerations (g's)	--
f.	head accelerations (g's)	1000

The recommended SAE instrumentation guidelines (SAE - J211a) suggests that these measurements be filtered with the channel classes listed above. However, since the data is digitized and subsequently digital filters are applied, the recommended practice cannot be followed precisely. This is due to the fact that the dynamic accuracy of the data channels specified in SAE - J211a are much less accurate than most digital filters. To be more specific, the following comparison is presented (refer to SAE - J211a):

1. The passband ripple ($a = \pm 0.5$) dB can be reduced with digital filters to as low as ±0.01 dB.

2. The overshoot frequency F_N, which is 5/3 times the corner frequency F_H can be reduced in a digital filter to as low as 3/2 the corner frequency.

3. The roll-off from the passband to the stop band cannot be specified in a digital filter. Instead, the frequency response curves

exceed, even for short filters, the sharpest roll off rate of -24 dB/octave.

4. The stopband attenuation, specified in J211a to -30 dB, can be made much lower, even for short filters, and can exceed -200 dB for medium length (N=50) filters.

It is therefore not recommended to use J211a as a guideline for specifying the dynamic accuracy of a digital filter. Instead, appropriate filters will be used based on the specific measurement being filtered. The following is therefore the list of the measurements, the "SAE recommended channel class," and the actual digital filter used.

Signal	Recommended class F_H/F_N	Applied (Equiv.) class $F_H/F_N/F_S$	Filter Number
sled deceleration	60/100	60/ 88/180	(1) or (4)
belt loads	60/100	180/250/450	(2) or (5)
femur forces	600/1000	180/250/450	(2) or (5)
chest accelerations	180/300	180/250/450	(2) or (5)
pelvis accelerations	---	180/250/450	(2) or (5)
head accelerations	1000/1650	360/460/720	(3) or (6)

The frequency response of these filters are shown in Figures 11, 12, 13, 14, 15, and 16 . The filtered signals of all the channels which were processed in the second contract year are presented in Appendices A and B.

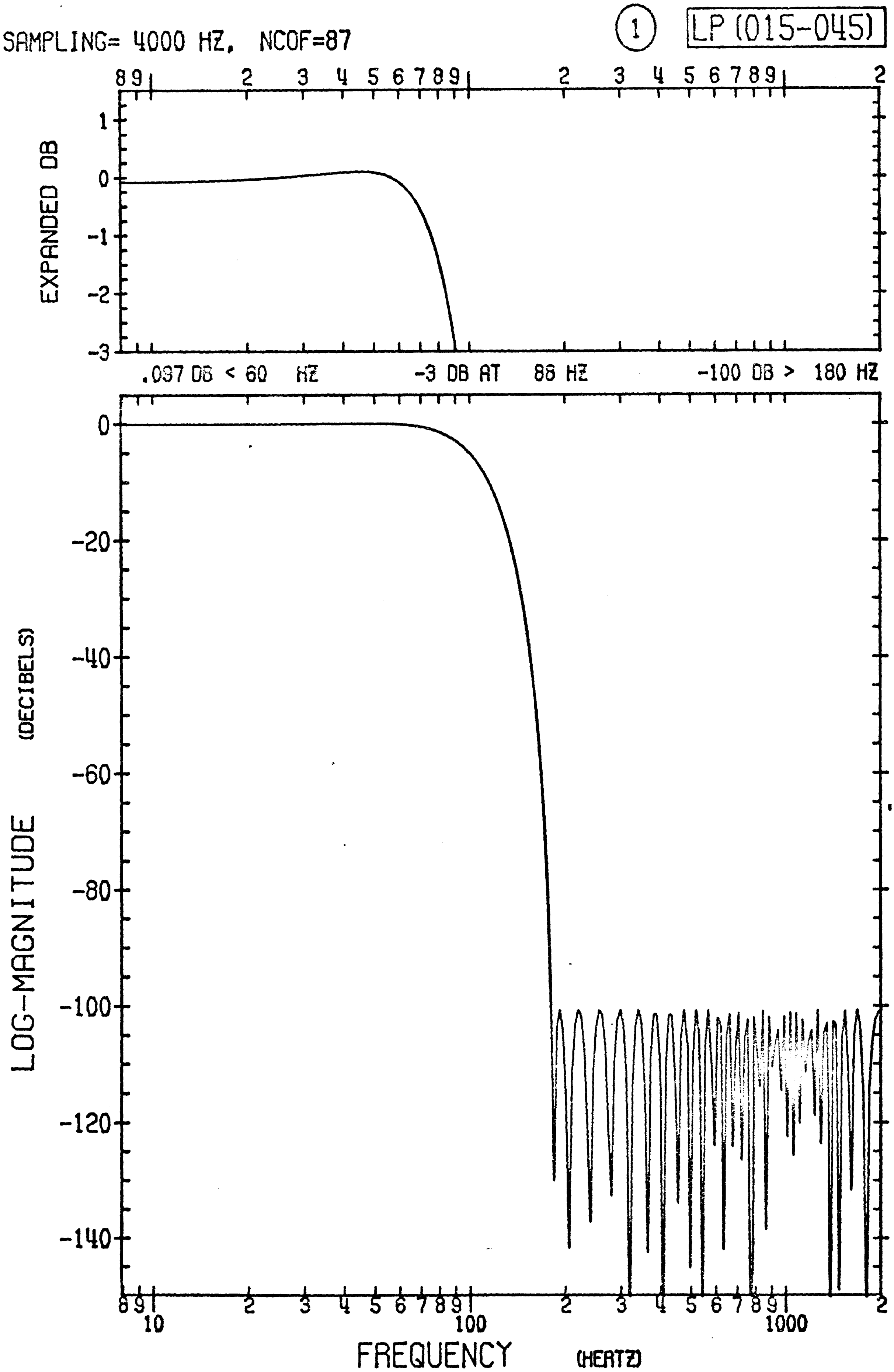


FIGURE 11. "CHANNEL CLASS 60" -- SAMPLING 4000 Hz

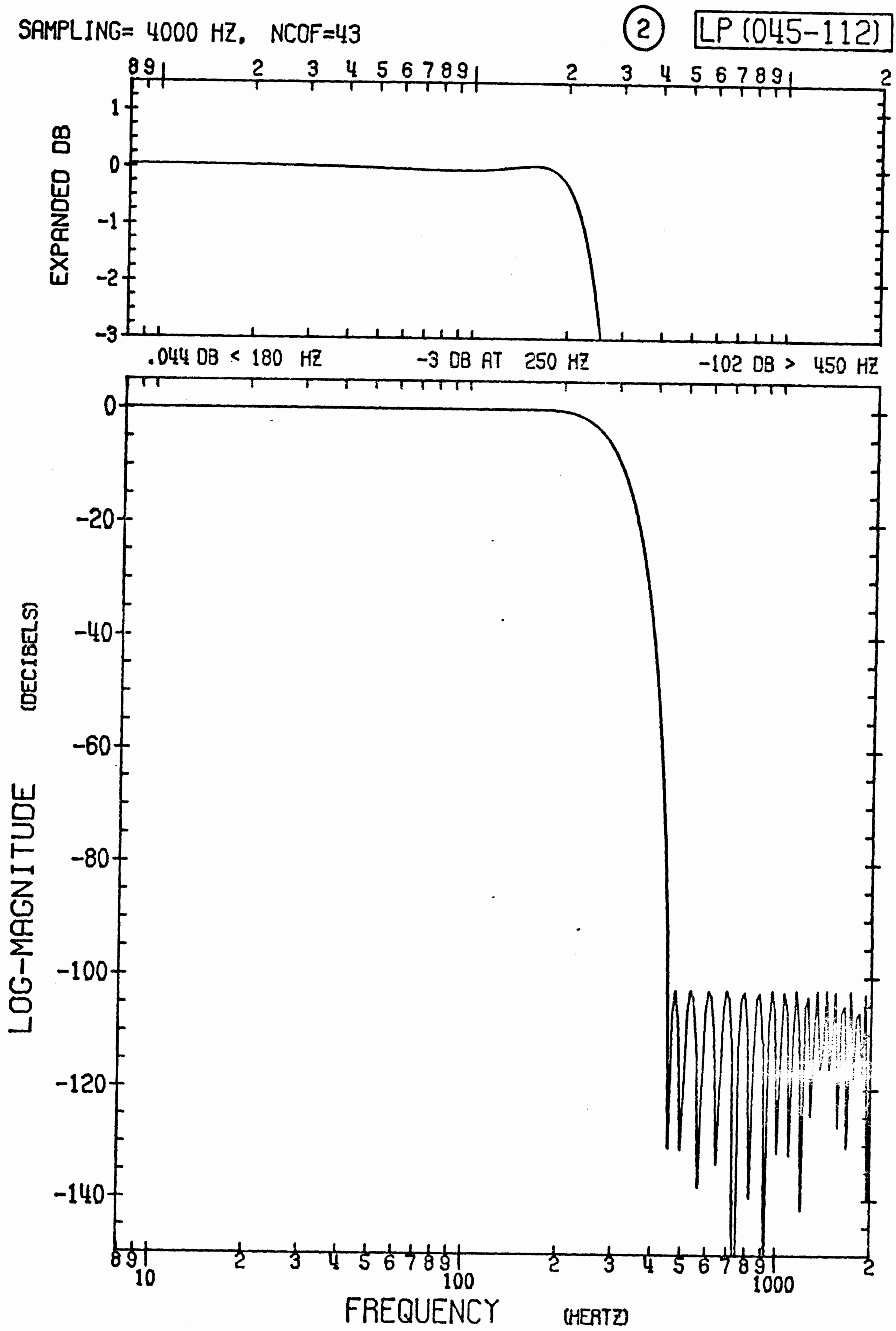


FIGURE 12. "CHANNEL CLASS 180" - SAMPLING 4000 Hz

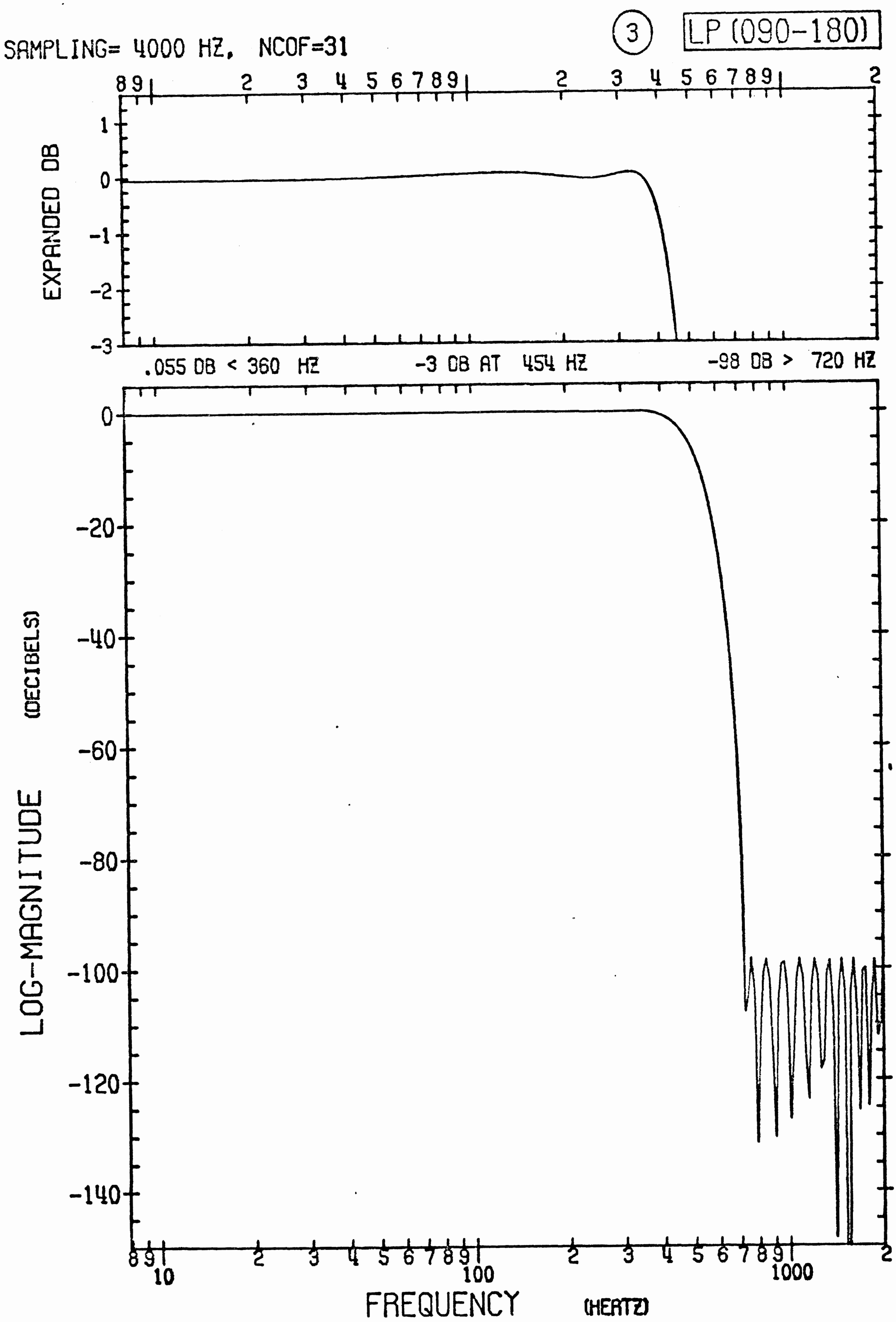


FIGURE 13. "CHANNEL CLASS" 360 -- SAMPLING 4000 Hz

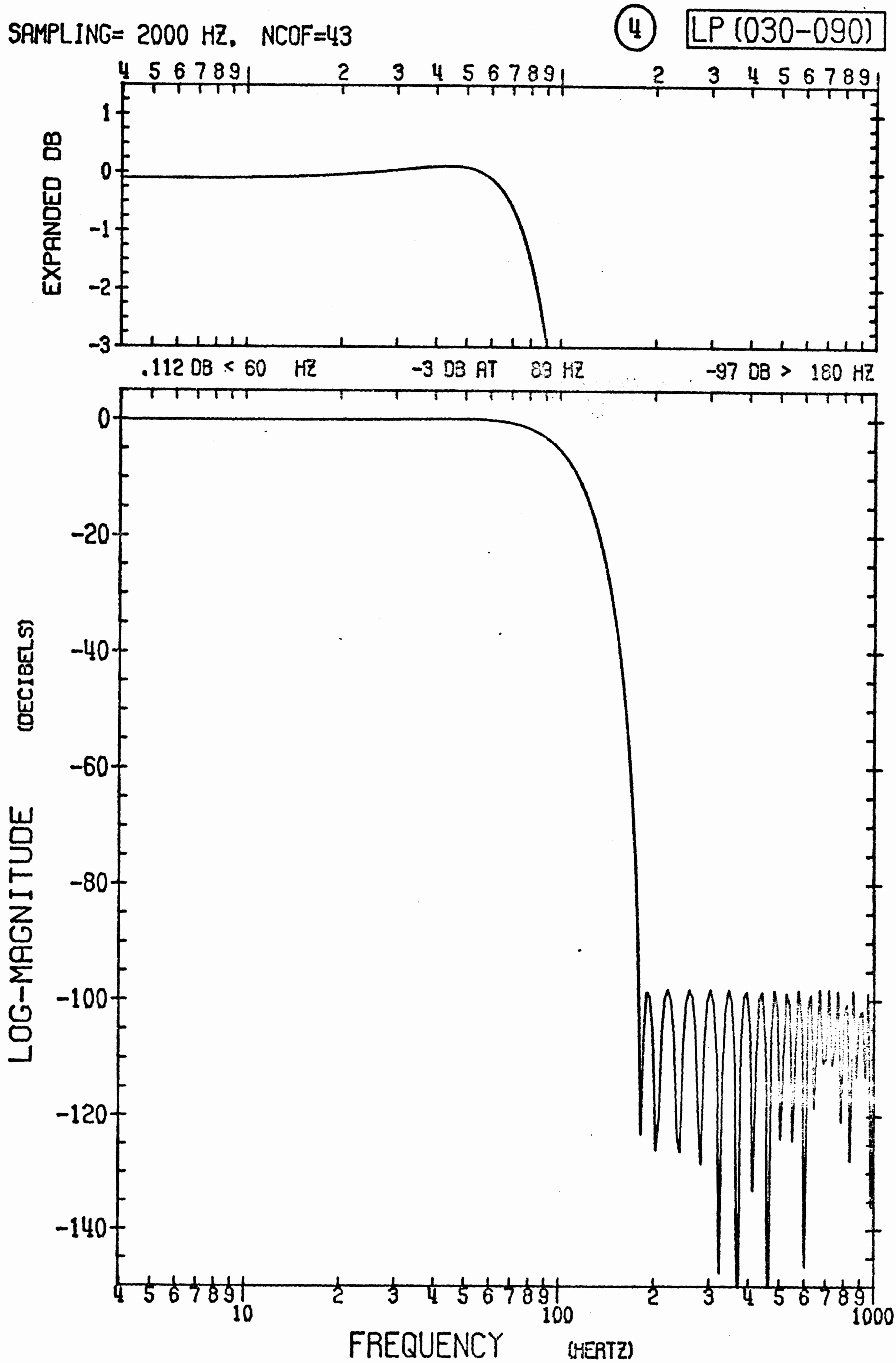


FIGURE 14. "CHANNEL CLASS" 60 -- SAMPLING 2000 Hz

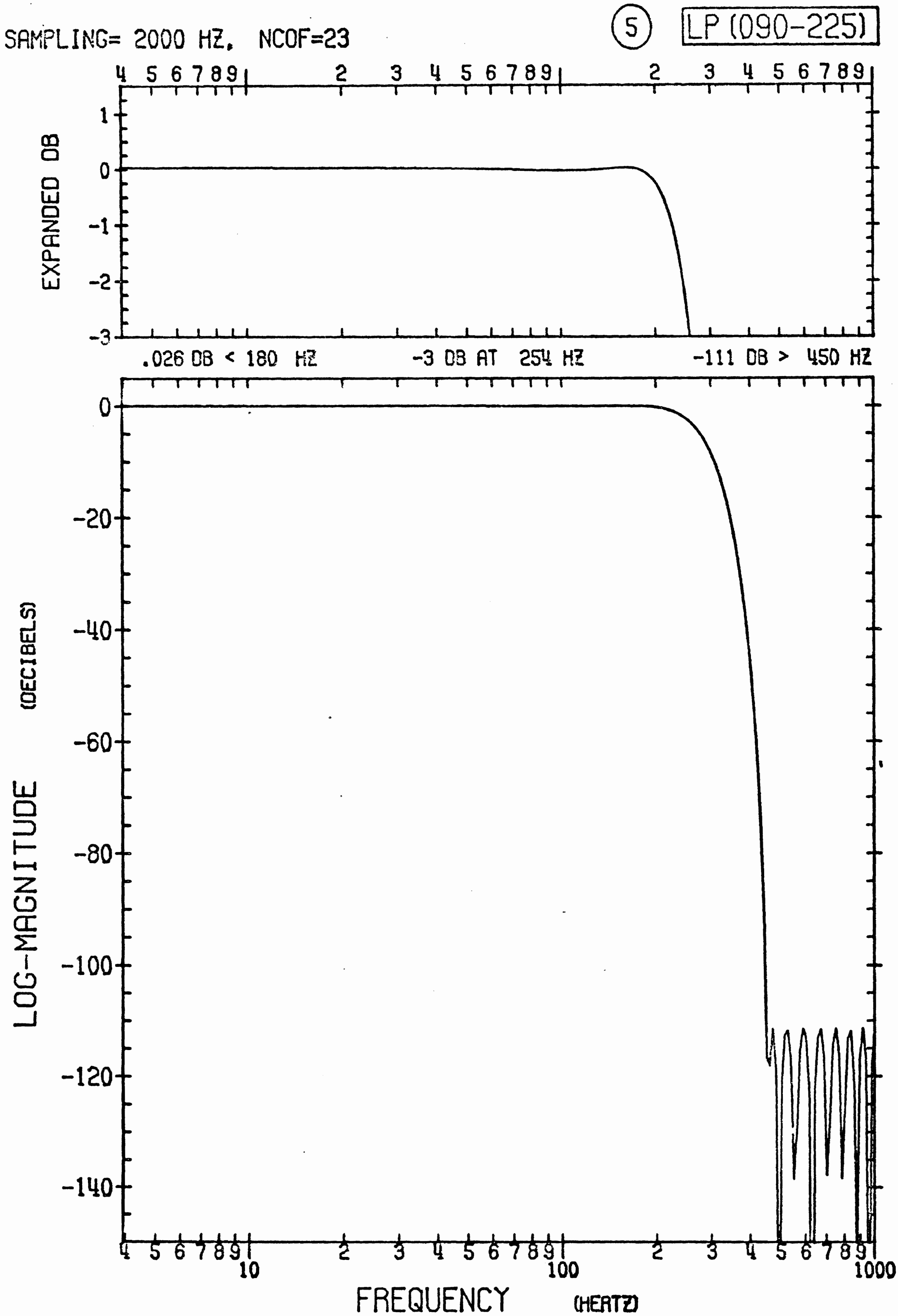


FIGURE 15. "CHANNEL CLASS" 180 -- SAMPLING 2000 Hz

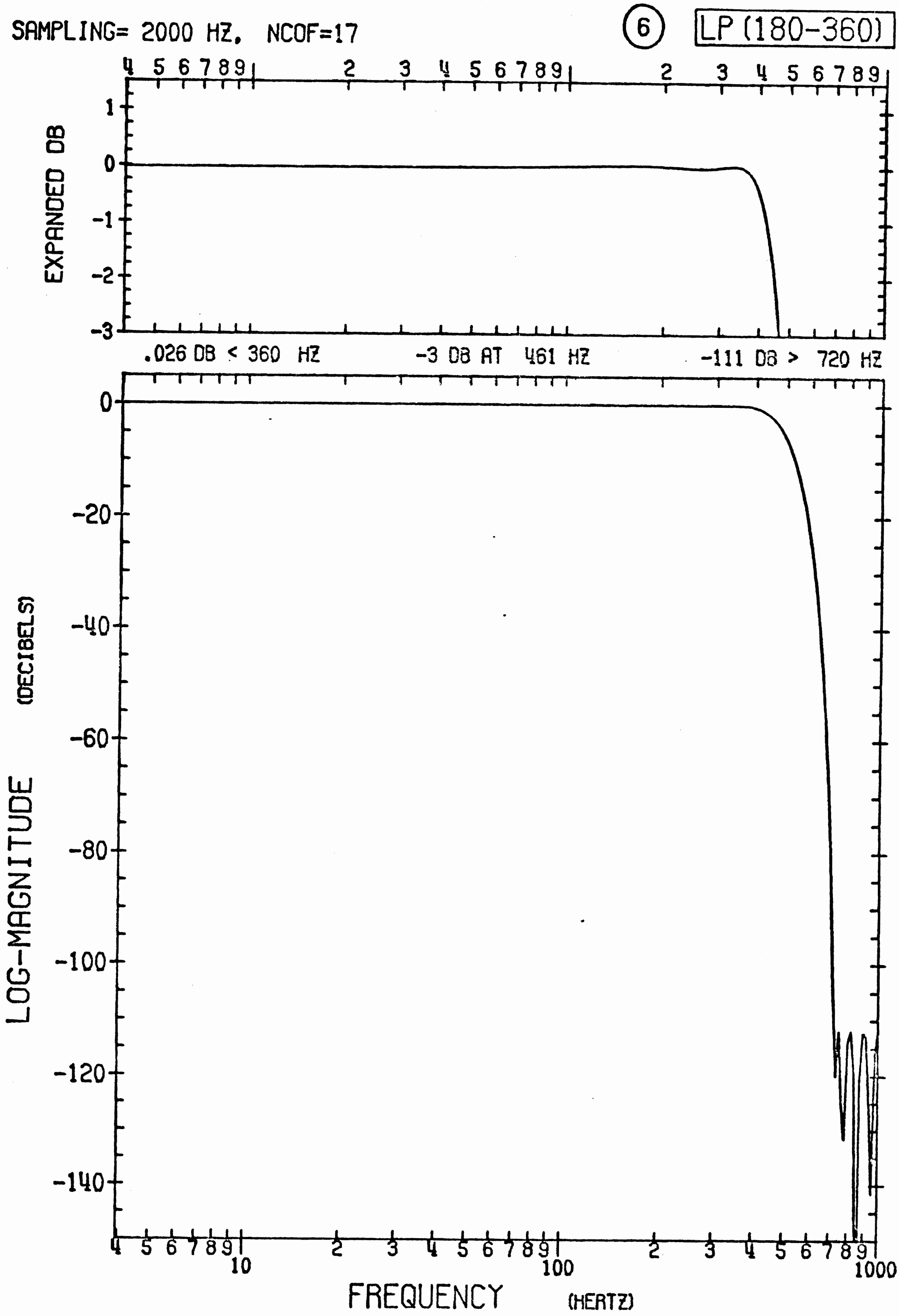


FIGURE 16. "CHANNEL CLASS" 360 -- SAMPLING 2000 Hz

5.3 3-D Rigid Body Motion Measurement

5.3.1 Kinematic Equations

The general 3-D motion of the rigid body, shown in Figure 17, can be described with kinematic equations which determine its six degrees of freedom at any instant of time.

Let P be the origin of an instrumentation frame $(\hat{e}_1, \hat{e}_2, \hat{e}_3)$ which is embedded in the rigid body. Let O be a fixed point in space and the origin of an inertial reference frame $(\hat{I}, \hat{J}, \hat{K})$.

Consider a body-point Q_1, embedded in the rigid body such that

$\vec{\rho}_1 = \overrightarrow{PQ}_1$

and let $\vec{R} = \overrightarrow{OP}$ be the position vector of the moving origin P. The position vector of point Q_1 with respect to the inertial space is then:

$$\vec{r}_1 = \overrightarrow{OQ}_1 = \vec{R} + \vec{\rho}_1 \tag{1}$$

the velocity and acceleration vectors of Q_1 are

$$\dot{\vec{r}} = \dot{\vec{R}} + \vec{\omega} \times \vec{\rho}_1 \tag{2}$$

and

$$\ddot{\vec{r}}_1 = \ddot{\vec{R}} + \dot{\vec{\omega}} \times \vec{\rho}_1 + \vec{\omega} \times (\vec{\omega} \times \vec{\rho}_1) \tag{3}$$

Equation (3) may be rewritten as 3 scalar equations by expressing each vector in any desired cartesian frame. The most convenient one is the moving reference frame $(\hat{e}_1, \hat{e}_2, \hat{e}_3)$. Thus,

$$\ddot{\vec{r}}_1 = a_{11}\, \hat{e}_1 + a_{21}\, \hat{e}_2 + a_{31}\, \hat{e}_2 \tag{4}$$

$$\ddot{\vec{R}} = A_1\, \hat{e}_1 + A_2\, \hat{e}_2 + A_3\, \hat{e}_3 \tag{5}$$

$$\vec{\rho}_1 = \rho_{11}\, \hat{e}_1 + \rho_{21}\, \hat{e}_2 + \rho_{31}\, \hat{e}_3 \tag{6}$$

$$\vec{\omega} = \omega_1\, \hat{e}_1 + \omega_2\, \hat{e}_2 + \omega_3\, \hat{e}_3 \tag{7}$$

$$\dot{\vec{\omega}} = \dot{\omega}_1\, \hat{e}_1 + \dot{\omega}_2\, \hat{e}_2 + \dot{\omega}_3\, \hat{e}_3 \tag{8}$$

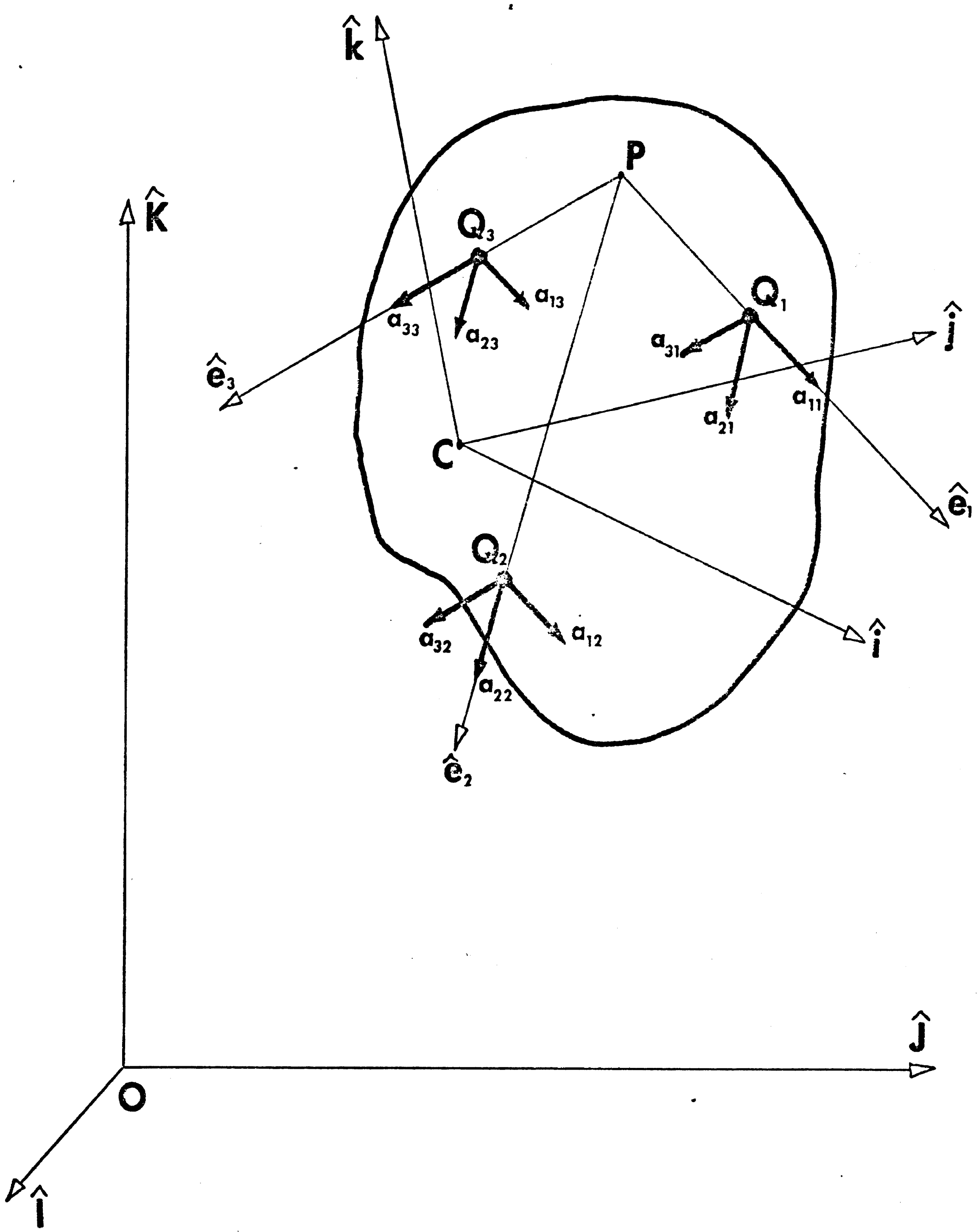


FIGURE 17. RIGID BODY COORDINATE SYSTEMS

Two additional points Q_2 and Q_3 such that:

$$\ddot{\vec{r}}_2 = a_{12}\,\hat{e}_1 + a_{22}\,\hat{e}_2 + a_{32}\,\hat{e}_3 \tag{9}$$

$$\ddot{\vec{r}}_3 = a_{13}\,\hat{e}_1 + a_{23}\,\hat{e}_2 + a_{33}\,\hat{e}_3 \tag{10}$$

and

$$\vec{\rho}_2 = \rho_{12}\,\hat{e}_1 + \rho_{22}\,\hat{e}_2 + \rho_{32}\,\hat{e}_3 \tag{11}$$

$$\vec{\rho}_3 = \rho_{13}\,\hat{e}_1 + \rho_{23}\,\hat{e}_2 + \rho_{33}\,\hat{e}_3 \tag{12}$$

may be added to the rigid body so that equation (3) may be written for Q_2 and Q_3 as:

$$\ddot{\vec{r}}_2 = \ddot{\vec{R}} + \dot{\vec{\omega}} \times \vec{\rho}_2 + \vec{\omega} \times (\vec{\omega} \times \vec{\rho}_2) \tag{13}$$

$$\ddot{\vec{r}}_3 = \ddot{\vec{R}} + \dot{\vec{\omega}} \times \vec{\rho}_3 + \vec{\omega} \times (\vec{\omega} \times \vec{\rho}_3) \tag{14}$$

Using equations (4) through (12), equations (3), (13) and (14) may be broken down into 9 scalar equations which contain 9 accelerations (which can be measured with linear accelerometers) and the 3 unknown components of each of $\ddot{\vec{R}}$, $\dot{\vec{\omega}}$ and $\vec{\omega}$.

These equations are greatly simplified if the 3 points, Q_1, Q_2, Q_3 are chosen on the instrumentation axes $\hat{e}_1$, $\hat{e}_2$, $\hat{e}_3$, respectively. Thus the expressions for $\vec{\rho}_1$, $\vec{\rho}_2$ and $\vec{\rho}_3$ become:

$$\vec{\rho}_1 = \rho_1\,\hat{e}_1 \tag{15}$$

$$\vec{\rho}_2 = \rho_2\,\hat{e}_2 \tag{16}$$

$$\vec{\rho}_3 = \rho_3\,\hat{e}_3 \tag{17}$$

and the 9 scalar equations become:

$$a_{11} = A_1 - \rho_1(\omega_2^2 + \omega_3^2) \tag{18}$$

$$a_{21} = A_2 + \rho_1(\dot{\omega}_3 + \omega_1\omega_2) \tag{19}$$

$$a_{31} = A_3 - \rho_1(\dot{\omega}_2 - \omega_3\omega_1) \tag{20}$$

$$a_{12} = A_1 - \rho_2(\dot{\omega}_3 - \omega_1\omega_2) \quad (21)$$

$$a_{22} = A_2 - \rho_2(\omega_3^2 + \omega_1^2) \quad (22)$$

$$a_{32} = A_3 + \rho_2(\dot{\omega}_1 + \omega_2\omega_3) \quad (23)$$

$$a_{13} = A_1 + \rho_3(\dot{\omega}_2 + \omega_3\omega_1) \quad (24)$$

$$a_{23} = A_2 - \rho_3(\dot{\omega}_1 - \omega_2\omega_3) \quad (25)$$

$$a_{33} = A_3 - \rho_3(\omega_1^2 + \omega_2^2) \quad (26)$$

5.3.2 Minimum-Input Method

There are several methods which have been suggested to deal with the 9 equations (18) through (26). A method which has been adopted at HSRI requires a minimum number of input acceleration readings. Although all the minimum-input methods are proven to be mathematically unstable, the HSRI method is presented here for the record, and because it has shown a limited successful applicability.

To simplify the problem, equations (18), (22) and (26) are disregarded because they are redundant, and because they do not contain components of the angular acceleration vector. This result in 6 equations and 6 unknowns which are the components of $\ddot{\vec{R}}$ and $\dot{\vec{\omega}}$, ($\vec{\omega}$ is not an unknown since it is the integral of $\dot{\vec{\omega}}$.) The required acceleration readings become what is termed the 2-2-2 combination of uniaxial accelerometers.

After some lengthy manipulations, the remaining six equations (19, 20, 21, 23, 24, 25) are partially uncoupled to yield the two sets of equations. The first is a set of 3 coupled, nonlinear, simultaneous, first order differential equations in $\dot{\omega}_1$, $\dot{\omega}_2$ and $\dot{\omega}_3$:

$$\begin{Bmatrix} \dot{\omega}_1 \\ \dot{\omega}_2 \\ \dot{\omega}_3 \end{Bmatrix} = [S] \begin{Bmatrix} \frac{a_{12} - a_{13}}{2} \\ \frac{a_{23} - a_{21}}{2} \\ \frac{a_{31} - a_{32}}{2} \end{Bmatrix} + [T] \begin{Bmatrix} \omega_2 \omega_3 \\ \omega_3 \omega_1 \\ \omega_1 \omega_2 \end{Bmatrix} \tag{27}$$

where

$$[S] = \begin{bmatrix} \frac{\rho_1}{\rho_2 \rho_3} & -\frac{1}{\rho_3} & -\frac{1}{\rho_2} \\ -\frac{1}{\rho_3} & \frac{\rho_2}{\rho_1 \rho_3} & -\frac{1}{\rho_1} \\ -\frac{1}{\rho_2} & -\frac{1}{\rho_1} & \frac{\rho_3}{\rho_1 \rho_2} \end{bmatrix} \tag{28}$$

and

$$[T] = \begin{bmatrix} 0 & \frac{\rho_1}{\rho_2} & -\frac{\rho_1}{\rho_3} \\ -\frac{\rho_2}{\rho_1} & 0 & \frac{\rho_2}{\rho_3} \\ \frac{\rho_3}{\rho_1} & -\frac{\rho_3}{\rho_2} & 0 \end{bmatrix} \tag{29}$$

The other is a set of 3 uncoupled algebraic equations in the 3 components of $\ddot{\vec{R}}$:

$$\begin{Bmatrix} A_1 \\ A_2 \\ A_3 \end{Bmatrix} = \begin{Bmatrix} \frac{a_{12} + a_{13}}{2} \\ \frac{a_{21} + a_{23}}{2} \\ \frac{a_{32} + a_{31}}{2} \end{Bmatrix} + [F] \begin{Bmatrix} \frac{a_{12} - a_{13}}{2} \\ \frac{a_{23} - a_{21}}{2} \\ \frac{a_{31} - a_{32}}{2} \end{Bmatrix} + [G] \begin{Bmatrix} \omega_2 \omega_3 \\ \omega_3 \omega_1 \\ \omega_1 \omega_2 \end{Bmatrix} \tag{30}$$

where

$$[F] = \begin{bmatrix} 0 & -\frac{\rho_2}{\rho_1} & \frac{\rho_3}{\rho_1} \\ \frac{\rho_1}{\rho_2} & 0 & -\frac{\rho_3}{\rho_2} \\ -\frac{\rho_1}{\rho_3} & \frac{\rho_2}{\rho_3} & 0 \end{bmatrix} \tag{31}$$

and

$$[G] = \begin{bmatrix} \frac{\rho_2\rho_3}{\rho_1} & -\rho_3 & -\rho_2 \\ -\rho_3 & \frac{\rho_3\rho_1}{\rho_2} & -\rho_1 \\ -\rho_2 & -\rho_1 & \frac{\rho_1\rho_2}{\rho_3} \end{bmatrix} \tag{32}$$

The forms of equations (27) and (30) are readily programmable since the matrices [S], [T], [F], and [G] are constant throughout the integration period. It can be shown mathematically that equations (27) are unstable. However, limited success was encountered where the integration is carried out up to a certain point, after which errors grow exponentially causing the integration to "blow up."

The integration is the first step toward a complete solution, after which equations (30) may be solved, then subsequent integrations and transformations lead to the final step of obtaining the three rotations- and three translations- time histories in inertial space.

5.3.3 Redundant-Input Methods

The instability of minimum-input methods has lead researchers to suggest the addition of more "redundant" acceleration readings and either avoid the integration altogether, or introduce a stabilizing feedback to the integration.

One method used at Wayne State University requires the mounting of a fourth point Q_4 at which 3 readings are obtained and added to the analysis of a 3-2-1 configuration. This method does not require any integration, and the solution for the angular accelerations is unique. However, the mounting of a 4-point system is considered to be cumbersome.

Three other methods are being implemented at HSRI, which do not require a 4th point mounting, but do result in 9 accelerometer readings. The first method is one used at Calspan: it requires 3 triaxial accelerometers but eventually boils down to an integration of 3 coupled, nonlinear simultaneous 1st order differential equations. Instability is expected to occur when readings contain gross errors, but it is expected that the "life" of the integration will be longer than other 6-acceleration methods.

The second 3-point, 9 acceleration method is developed at HSRI. The solution is obtained algebraically, but it results in double roots for the angular accelerations. Continuity of physical motion and initial conditions are used to select the proper roots. However, when the roots are very close, this technique may not prove very powerful.

The third redundant method which uses a 3-point mount is a combination of the above two methods. This method is not fully developed, but it will be primarily a "checked" integration. The integration may be either that of the 6 acceleration method, or that of the Calspan method, and checking will be done against the 3 redundant readings or against one of the roots of the algebraic method.

5.3.4 Method A: HSRI Algebraic Method

Equations (18) through (26) may be manipulated, first by eliminating $\dot{\omega}_1$, $\dot{\omega}_2$, $\dot{\omega}_3$, then by eliminating A_1, A_2 and A_3, from then resulting 6 equations. The outcome is a set of 3 nonlinear simultaneous algebraic equations in ω_1, ω_2 and ω_3:

$$\rho_2\omega_1^2 + \rho_1\omega_2^2 + (\rho_1+\rho_2)\left[\omega_1\omega_2+\omega_3^2\right] + \left[(a_{11}+a_{22})-(a_{12}+a_{21})\right] = 0 \tag{33}$$

$$\rho_3\omega_2^2 + \rho_2\omega_3^2 + (\rho_2+\rho_3)\left[\omega_2\omega_3+\omega_1^2\right] + \left[(a_{22}+a_{33})-(a_{23}+a_{32})\right] = 0 \tag{34}$$

$$\rho_1\omega_3^2 + \rho_3\omega_1^2 + (\rho_3+\rho_1)\left[\omega_3\omega_1+\omega_2^2\right] + \left[(a_{33}+a_{11})-(a_{31}+a_{13})\right] = 0 \tag{35}$$

let

$$G_1 = (a_{11} + a_{22}) - (a_{12} + a_{21}) \tag{36}$$

$$G_2 = (a_{22} + a_{33}) - (a_{23} + a_{32}) \tag{37}$$

$$G_3 = (a_{33} + a_{11}) - (a_{31} + a_{13}) \tag{38}$$

and let

$$F_1 = G_1 + \rho_2\omega_1^2 + \rho_1\omega_2^2 + (\rho_1+\rho_2)\left[\omega_1\omega_2+\omega_3^2\right] \tag{39}$$

$$F_2 = G_2 + \rho_3\omega_2^2 + \rho_2\omega_3^2 + (\rho_2+\rho_3)\left[\omega_2\omega_3+\omega_1^2\right] \tag{40}$$

$$F_3 = G_3 + \rho_1\omega_3^2 + \rho_3\omega_1^2 + (\rho_3+\rho_1)\left[\omega_3\omega_1+\omega_2^2\right] \tag{41}$$

To solve equations (33, 34, 35) simultaneously for ω_1, ω_2, ω_3, a standard IBM-SSP routine, FMFP is used. This routine search for the roots ω_1, ω_2, ω_3 which minimize any given function V. Such a function is constructed as:

$$V \equiv \frac{1}{2}\left[F_1^2 + F_2^2 + F_3^2\right] \tag{42}$$

This function is always zero and the search should produce a zero minimum. Therefore, the initial guess at a minimum, required by FMFP, is taken as zero. In addition, FMFP requires the values of the partial derivatives of V with respect to the unknowns ω_1, ω_2, ω_3:

$$\frac{\partial V}{\partial \omega_1} = F_1 \frac{\partial F_1}{\partial \omega_1} + F_2 \frac{\partial F_2}{\partial \omega} + F_3 \frac{\partial F_3}{\partial \omega} \tag{43}$$

$$\frac{\partial V}{\partial \omega_2} = F_1 \frac{\partial F_1}{\partial \omega_2} + F_2 \frac{\partial F_2}{\partial \omega_2} + F_3 \frac{\partial F_3}{\partial \omega_2} \tag{44}$$

$$\frac{\partial V}{\partial \omega_3} = F_1 \frac{\partial F_1}{\partial \omega_3} + F_2 \frac{\partial F_2}{\partial \omega_3} + F_3 \frac{\partial F_3}{\partial \omega_3} \tag{45}$$

where $\partial F/\partial \omega$ terms are easily obtained from the definitions of F_1, F_2 and F_3:

$$\frac{\partial F_1}{\partial \omega_1} = 2\rho_2 \omega_1 + (\rho_1 + \rho_2)\omega_2 \tag{46}$$

$$\frac{\partial F_2}{\partial \omega_1} = 2(\rho_2 + \rho_3)\omega_1 \tag{47}$$

$$\frac{\partial F_3}{\partial \omega_1} = 2\rho_3 \omega_1 + (\rho_3 + \rho_1)\omega_3 \tag{48}$$

$$\frac{\partial F_1}{\partial \omega_2} = 2\rho_1 \omega_2 + (\rho_1 + \rho_2)\omega_1 \tag{49}$$

$$\frac{\partial F_2}{\partial \omega_2} = 2\rho_3 \omega_2 + (\rho_2 + \rho_3)\omega_3 \tag{50}$$

$$\frac{\partial F_3}{\partial \omega_2} = 2(\rho_3 + \rho_1)\omega_2 \tag{51}$$

$$\frac{\partial F_1}{\partial \omega_3} = 2(\rho_1 + \rho_2)\omega_3 \tag{52}$$

$$\frac{\partial F_2}{\partial \omega_3} = 2\rho_2 \omega_3 + (\rho_2 + \rho_3)\omega_2 \tag{53}$$

$$\frac{\partial F_3}{\partial \omega_3} = 2\rho_1 \omega_3 + (\rho_3 + \rho_1)\omega_1 \tag{54}$$

The solution of equations (33, 34, 35) is repeated at each time instant, and is independent from past history of the ω's. However, the previous values of $(\omega_1, \omega_2, \omega_3)$ are used to provide guesses for the initial values from which the iteration procedure starts.

Note that if the expressions for F_1, F_2, F_3 were satisfied for a set of $(\omega_1, \omega_2, \omega_3)$, they are also satisfied for the negative set $(-\omega_1, -\omega_2, -\omega_3)$. It is therefore conceivable that the minimization routine FMFP would return the negative set of ω's. To select the correct set, it is first estimated with the approximate formulae:

$$\omega_1^* = \omega_1 + \dot{\omega}_1 \Delta t \tag{55}$$

$$\omega_2^* = \omega_2 + \dot{\omega}_2 \Delta t \tag{56}$$

$$\omega_3^* = \omega_3 + \dot{\omega}_3 \Delta t \tag{57}$$

where $(\omega_1, \omega_2, \omega_3)$ are the angular velocities taken at the previous time instant, Δt is the time step, and $(\dot{\omega}_1, \dot{\omega}_2, \dot{\omega}_3)$ are the angular velocities at the previous point, obtained from equation (27). If the values returned by FMFP are within a given tolerance from the estimated values, then the returned values are retained. If the returned values are within a given tolerance from the negative of the estimated values, the returned values must be the negative set, and what is retained is the negative of the returned values.

5.3.5 Method B: HSRI Hybrid Method

This method is still in the developing stages, and promises to be more efficient than the algebraic method alone.

Essentially, this method integrates equations (27) using 6 accelerations only. At the end of each time step, the predictor-corrector integrator returns with a set of ω's and $\dot{\omega}$'s. One additional correction is made to these values based on the differences between each of the unused 3 acceleration readings and the corresponding computed values. This feedback acts as a stabilizing loop in the iteration for a solution. At the present time, it has not been decided whether to include this correction in the integration routine (i.e., write a new integration routine), or to add the correction after the integration has been completed in one time step. In this case, the same integration routine would be used, knowing that the recent history of the variables, which is kept by the integrator may have been altered.

This feedback method is not a new idea, since it is an essential part of any stable control system.

5.3.6 Method C: Calspan Least-Squares Method

This method was developed at Calspan to deal with as many as 12 triaxial accelerometers mounted on one vehicle (36 readings). Since only 6 acceleration readings are independent for a rigid body, the redundant readings must be related with constraint equations. However, errors in the calibration and noise of the signals result usually in inconsistent readings. The redundancy is utilized to produce six equations to be integrated. The mathematical instability is not solved, but the input is improved. Following is a presentation of this method, in which it is assumed that the acceleration readings are given along the anatomical directions.

Let Q_1, Q_2, Q_3 be located in the rigid body, which has $(\hat{i},\hat{j},\hat{k})$ for anatomical frame and C as origin of this frame. With C as a reference point,

$$\begin{Bmatrix} \overrightarrow{CQ_1} \\ \overrightarrow{CQ_2} \\ \overrightarrow{CQ_3} \end{Bmatrix} = \begin{bmatrix} \delta_{11} & \delta_{21} & \delta_{31} \\ \delta_{12} & \delta_{22} & \delta_{32} \\ \delta_{13} & \delta_{23} & \delta_{33} \end{bmatrix} \begin{Bmatrix} \hat{i} \\ \hat{j} \\ \hat{k} \end{Bmatrix} \tag{58}$$

Consider now the centroid Q_0 of Q_1, Q_2, Q_3, defined by

$$\begin{Bmatrix} \delta_{10} \\ \delta_{20} \\ \delta_{30} \end{Bmatrix} = \frac{1}{3} \begin{Bmatrix} \delta_{11} + \delta_{12} + \delta_{13} \\ \delta_{21} + \delta_{22} + \delta_{23} \\ \delta_{31} + \delta_{32} + \delta_{33} \end{Bmatrix} \tag{59}$$

then let τ be the matrix of coordinates of Q_1, Q_2, Q_3 relative to Q_0 (expressed in $\hat{i},\hat{j},\hat{k}$), i.e.:

$$\tau = \begin{bmatrix} \delta_{11}-\delta_{10} & \delta_{21}-\delta_{20} & \delta_{31}-\delta_{30} \\ \delta_{12}-\delta_{10} & \delta_{22}-\delta_{20} & \delta_{32}-\delta_{30} \\ \delta_{13}-\delta_{10} & \delta_{23}-\delta_{20} & \delta_{33}-\delta_{30} \end{bmatrix} \tag{60}$$

Finally, the 3 absolute acceleration vectors $\vec{a}_1$, $\vec{a}_2$, $\vec{a}_3$, measured at Q_1, Q_2, Q_3 and expressed in the anatomical frame $(\hat{i},\hat{j},\hat{k})$ are:

$$\begin{Bmatrix} \vec{a}_1 \\ \vec{a}_2 \\ \vec{a}_3 \end{Bmatrix} = \begin{bmatrix} a_{11} & a_{21} & a_{31} \\ a_{21} & a_{22} & a_{32} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{Bmatrix} \hat{i} \\ \hat{j} \\ \hat{k} \end{Bmatrix} \tag{61}$$

As the rigid body moves in inertial space $(\hat{I},\hat{J},\hat{K})$, its orientation is defined by the Euler transformation matrix, which is made up of the direction cosines of the anatomical unit vectors $\hat{i}$, $\hat{j}$ and $\hat{k}$ with respect to the inertial frame $(\hat{I},\hat{J},\hat{K})$. Let D be that matrix:

$$\begin{Bmatrix} \hat{i} \\ \hat{j} \\ \hat{k} \end{Bmatrix} = \begin{bmatrix} D \end{bmatrix} \begin{Bmatrix} \hat{I} \\ \hat{J} \\ \hat{K} \end{Bmatrix} \tag{62}$$

The acceleration of a point Q_i $(i = 1,2,3)$ is given by equation (3)

$$\ddot{\vec{r}}_i = \ddot{\vec{r}}_0 + \dot{\vec{\omega}} \times \vec{\rho}_i + \vec{\omega} \times (\vec{\omega} \times \vec{\rho}_i) \tag{63}$$

where $\ddot{\vec{r}}_0$ is the acceleration vector of any reference point, $\dot{\vec{\omega}}$ and $\vec{\omega}$ are the angular acceleration and velocity vectors and $\vec{\rho}_i$ is the position vector of Q_i relative to the reference point. Equation (63) may be expressed in the inertial frame, and the centroid Q_o may be taken as the reference point.

The position vector ρ_i is known relative to the anatomical frame:

$$\vec{\rho}_i = [\tau_{1i} \quad \tau_{2i} \quad \tau_{3i}] \begin{Bmatrix} \hat{i} \\ \hat{j} \\ \hat{k} \end{Bmatrix} \tag{64}$$

or

$$\vec{\rho}_i = [\ \tau_i\ ] \begin{Bmatrix} \hat{i} \\ \hat{j} \\ \hat{k} \end{Bmatrix} \tag{65}$$

where τ_i is the line vector given in the matrix τ:

$$\vec{\rho}_i = [\ \tau_i\ ]\ [D] \begin{Bmatrix} \hat{I} \\ \hat{J} \\ \hat{K} \end{Bmatrix} \tag{66}$$

The components of $\vec{\rho}_i$, another line vector, may be transformed into a column vector simply by transposing:

$$\rho_i = D^{-1}\ \tau_i \tag{67}$$

where τ_i is now a column vector, and D^{-1} is the transpose of D (since D is orthogonal, its inverse equals its transpose).

Now, equation (63) may be written in tensor form as:

$$\ddot{r}_i = \ddot{r}_o + D^{-1}\ \dot{\omega} \times \tau_i + D^{-1}\ \omega \times \omega \times \tau_i \tag{68}$$

However, $\ddot{r}_i$ is not measured, but D $\ddot{r}_i$ is measured, i.e.:

$$a_i = D\ \ddot{r}_i = D\ \ddot{r}_o + \dot{\omega} \times \tau_i + \omega \times \omega \times \tau_i \tag{69}$$

Finally, equation (69) may be rewritten for $i = 1, 2, 3$, in the compact form

$$D_3 \ddot{r} - R \dot{\omega} + V = 0 \tag{70}$$

where the following definitions are used:

$$D_3 = \begin{bmatrix} D \\ D \\ D \end{bmatrix} \quad \text{(9 x 3 matrix)} \tag{71}$$

$$R = \begin{bmatrix} \tau_1 X \\ \tau_2 X \\ \tau_3 X \end{bmatrix} \quad \text{(9 x 3 matrix)} \quad \text{with} \quad [\tau_i X] = \begin{bmatrix} 0 & -\tau_{i3} & \tau_{i2} \\ \tau_{i3} & 0 & -\tau_{i1} \\ -\tau_{i2} & \tau_{i1} & 0 \end{bmatrix} \tag{72}$$

$$V = \begin{Bmatrix} \omega X & \omega X & \tau_1 - a_1 \\ \omega X & \omega X & \tau_2 - a_2 \\ \omega X & \omega X & \tau_3 - a_3 \end{Bmatrix} \quad \text{(9 x 1 matrix)} \quad [\omega X] = \begin{bmatrix} 0 & -\omega_3 & \omega_2 \\ \omega_3 & 0 & -\omega_1 \\ -\omega_2 & \omega_1 & 0 \end{bmatrix} \tag{73}$$

$$\varepsilon = D_3 \ddot{r} - R \dot{\omega} + V \tag{74}$$

Assume that the errors in the accelerometer readings have a zero mean and a co-variance matrix ρ. Then the quadratic form of equation (74),

$$\varepsilon^T \rho^{-1} \varepsilon = [D_3 \ddot{r} - R \dot{\omega} + V]^T \rho^{-1} [D_3 \ddot{r} - R \dot{\omega} + V] \tag{75}$$

is a measure of the squared weighted error. Assume further that the errors are independent and have equal variance, then ρ may be replaced by the identity matrix I. Finally, expressions for $\dot{\omega}_1$, $\dot{\omega}_2$, $\dot{\omega}_3$ may be obtained individually by minimizing the squared error of equation (75).

This is done by differentiating with respect to each of $\dot{\omega}_1$, $\dot{\omega}_2$, $\dot{\omega}_3$, and setting the partial derivatives equal to zero:

$$0 = \begin{Bmatrix} \partial[\varepsilon^T\varepsilon]/\partial\omega_1 \\ \partial[\varepsilon^T\varepsilon]/\partial\omega_2 \\ \partial[\varepsilon^T\varepsilon]/\partial\omega_3 \end{Bmatrix} = -R^T D_3 \ddot{r} + R^T R \dot{\omega} - R^T V \qquad (76)$$

Since Q_0 is the geometric center of Q_1, Q_2, Q_3

$$\tau_1 + \tau_2 + \tau_3 = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} \qquad (77)$$

it may be shown that therefore:

$$D_3^T R = 0 \qquad (78)$$

hence

$$\dot{\omega} = (R^T R)^{-1} R^T V \qquad (79)$$

After some manipulation, it can be shown that V may be replaced by another 9 x 1 matrix vector:

$$U = \begin{Bmatrix} (\omega \cdot \tau_1)\,\omega - a_1 \\ (\omega \cdot \tau_2)\,\omega - a_2 \\ (\omega \cdot \tau_3)\,\omega - a_3 \end{Bmatrix} \qquad (80)$$

so that

$$\dot{\omega} = [(R^T R)^{-1} R^T]\, U \qquad (81)$$

The matrix $[(R^T R)^{-1} R^T]$ is a constant matrix and can be prepared prior to the integration. Once the angular acceleration and velocity vectors are computed, the remainder of the analysis is straight-forward.

5.3.7 Motion in Inertial Space

The angular acceleration and velocity vector, obtained in any of the above described methods, are expressed in the anatomical frame

$$\dot{\vec{\omega}} = \dot{\omega}_1 \hat{i} + \dot{\omega}_2 \hat{j} + \dot{\omega}_3 \hat{k} \tag{82}$$

$$\vec{\omega} = \omega_1 \hat{i} + \omega_2 \hat{j} + \omega_3 \hat{k} \tag{83}$$

If the acceleration readings were directly employed in the solution (methods A and B), then $\dot{\vec{\omega}}$ and $\vec{\omega}$ are expressed in the instrumentation frame $(\hat{e}_1,\hat{e}_2,\hat{e}_3)$, and must therefore be transformed to anatomical $(\hat{i},\hat{j},\hat{k})$

$$[\dot{\omega}] = [\dot{\omega}] [E] \tag{84}$$

$$[\omega] = [\omega] [E] \tag{85}$$

where [E] is defined by

$$\begin{Bmatrix} \hat{e}_1 \\ \hat{e}_2 \\ \hat{e}_3 \end{Bmatrix} = [E] \begin{Bmatrix} \hat{i} \\ \hat{j} \\ \hat{k} \end{Bmatrix} \tag{86}$$

If on the other hand, the acceleration readings are first transformed to $(\hat{i},\hat{j},\hat{k})$, then, method C results in $\dot{\vec{\omega}}$ and $\vec{\omega}$ directly expressed in anatomical $(\hat{i},\hat{j},\hat{k})$.

In either case, the constant transformation matrix [E] must be known. A technique was developed to obtain [E] using two orthogonal x-rays of the head and is described in detail in Appendix C.

The next step in obtaining a complete solution is to determine the orientation of the rigid body in inertial frame. This is defined by matrix [D] given in equation (62), in which [D] is the Euler matrix:

$$
[D] = \begin{bmatrix} \cos\psi\cos\theta & \sin\psi\cos\theta & -\sin\theta \\ \begin{matrix}\cos\psi\sin\theta\sin\phi \\ -\sin\psi\cos\phi\end{matrix} & \begin{matrix}\cos\psi\cos\phi \\ +\sin\psi\sin\theta\sin\phi\end{matrix} & \cos\theta\sin\phi \\ \begin{matrix}\sin\psi\sin\phi \\ +\cos\psi\sin\theta\cos\phi\end{matrix} & \begin{matrix}-\cos\psi\sin\phi \\ +\sin\psi\sin\theta\cos\phi\end{matrix} & \cos\theta\cos\phi \end{bmatrix} \tag{87}
$$

The three Euler angles, yaw (ψ), pitch (θ) and roll (ϕ) are defined as follows. Assume that initially, the rigid body's anatomical axes ($\hat{i},\hat{j},\hat{k}$) coincides with the inertial frame ($\hat{I},\hat{J},\hat{K}$). Then, yaw is defined as a positive rotation of magnitude ψ about the $\hat{k}$-axis, resulting in an intermediate frame ($\hat{i}^*$, $\hat{j}^*$, $\hat{k}^*$). Next is pitch which is defined as a positive rotation of magnitude θ about the new $\hat{j}^*$-axis, resulting in a second intermediate frame ($\hat{i}^{**}$, $\hat{j}^{**}$, $\hat{k}^{**}$). Finally, the roll is defined as a positive rotation of magnitude ϕ about the newest $\hat{i}^{**}$-axis, resulting in the desired frame ($\hat{i},\hat{j},\hat{k}$). Therefore, the orientation of the anatomical frame in inertial space can completely be defined by specifying 3 ordered independent rotations called the Euler angles.

It can be shown from the definition of the Euler angles that the angular velocity vector is the sum of three angular rates:

$$
\vec{\omega} = \vec{\dot{\psi}} + \vec{\dot{\theta}} + \vec{\dot{\phi}} \tag{88}
$$

This is true even though the 3 vectors $\vec{\dot{\psi}}$, $\vec{\dot{\theta}}$, and $\vec{\dot{\phi}}$ are not, in general, mutually orthogonal. Equation (88) may be projected on each of the anatomical axes so that

$$\omega_1 = \text{proj}[\vec{\dot{\psi}} + \vec{\dot{\theta}} + \vec{\dot{\phi}}] \text{ on } \hat{i} \tag{89}$$

$$\omega_2 = \text{proj}[\vec{\dot{\psi}} + \vec{\dot{\theta}} + \vec{\dot{\phi}}] \text{ on } \hat{j} \tag{90}$$

$$\omega_3 = \text{proj}[\vec{\dot{\psi}} + \vec{\dot{\theta}} + \vec{\dot{\phi}}] \text{ on } \hat{k} \tag{91}$$

or

$$\omega_1 = \dot{\phi} - \dot{\psi} \sin\theta \tag{92}$$

$$\omega_2 = \dot{\theta} \cos\phi + \dot{\psi} \cos\theta \sin\phi \tag{93}$$

$$\omega_3 = \dot{\psi} \cos\theta \cos\phi - \dot{\theta} \sin\phi \tag{94}$$

Since ω_1, ω_2 and ω_3 are known at this stage, equations (92), (93), and (94) may be solved for the Euler angular rates:

$$\begin{Bmatrix} \dot{\psi} \\ \dot{\theta} \\ \dot{\phi} \end{Bmatrix} = \frac{1}{\cos\theta} \begin{bmatrix} 0 & \sin\phi & \cos\phi \\ 0 & \cos\phi & -\sin\phi \\ 1 & \sin\phi\sin\theta & \cos\phi\sin\theta \end{bmatrix} \begin{Bmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \end{Bmatrix} \tag{95}$$

The Euler angular rates are therefore defined except when $\theta = \pm 90°$. This case, known as the "Gimbal lock," can be avoided by switching to another set of Euler angles. However, a numerical procedure was improvised for this case to deal with this problem without switching Euler set, and has been satisfactory.

Equation (95) can be integrated to obtain the Euler angles as functions of time, which are used in determining the transformation matrix [D] at each instant of time.

After determining the 3 rotational degrees of freedom, the 3 translational degrees of freedom are to be computed. These are defined as the acceleration, velocity and position vectors of a body-point in inertial frame. To this end, the motion of a convenient reference point must be known. Depending on the method used, this point may be the origin C of the anatomical frame, or the centroid Q_0 of Q_1, Q_2, Q_3, whose location in the anatomical frame is known. Also, the location of the body-point in the body-frame is assumed to be known. This may be the center of mass of the head, or any other point of interest. Then,

$$\ddot{\vec{r}}_B = \ddot{\vec{R}} + \dot{\vec{\omega}} \times \vec{\rho}_B + \vec{\omega} \times (\vec{\omega} \times \vec{\rho}_B) \qquad (96)$$

where $\vec{\rho}_B$ is the position vector of B (body-point) in the anatomical frame, $\ddot{\vec{R}}$ is the acceleration vector of the reference point obtained as the algebraic average of the 3 triaxial readings (if Q_0 is used) or obtained with equation (30) if the origin C is used.

Now given the acceleration of B in anatomical $(\hat{i},\hat{j},\hat{k})$, and given the Euler transformation matrix, the absolute acceleration vector of B may be expressed in the inertial frame:

$$\ddot{\vec{r}}_B = \ddot{X}\,\hat{I} + \ddot{Y}\,\hat{J} + \ddot{Z}\,\hat{K} \qquad (97)$$

Finally, $\ddot{X}(t)$, $\ddot{Y}(t)$, $\ddot{Z}(t)$ are integrated independently to yield the velocities $\dot{X}(t)$, $\dot{Y}(t)$ and $\dot{Z}(t)$, then integrated again to obtain the three translational degrees of freedom $X(t)$, $Y(t)$, $Z(t)$.

5.4 Severity of Impact Analysis

To determine the severity of impact, accelerations (directly recorded or indirectly computed) are processed to determine the Severity Index and/or the Head Injury Criterion. Those signals which are not analyzed are presented "as is." The programs for these analyses have been written but not incorporated in the processing package.

5.4.1 Gadd Severity Index

Given an acceleration pulse a(t), of duration T, the Gadd severity is defined as

$$GSI = \int_0^T [A(t)]^{2.5}\, dt \qquad (98)$$

where a(t) is expressed in g's and dt in seconds. The GSI is computed for the AP, SI, LR components and their resultant accelerations at a body-point on the head (center of mass) and at the thoracic location of the accelerometer.

5.4.2 Head Injury Criterion

The HIC is defined by:

$$HIC = [\bar{A}]^{2.5}\, \Delta t \qquad (99)$$

where

$$\bar{A} = \frac{1}{\Delta t} \int_{t_2}^{t_1} a(t)\, dt \qquad (100)$$

and a(t) = resultant acceleration in g's

t = time in seconds

t_1 = any arbitrary time point in the pulse

t_2 = for a given t_1, a time point in the pulse which maximizes HIC.

$$\Delta t = (t_1 - t_2)$$

The HIC is computed only for resultant accelerations at the center of mass of the head.

5.4.3 Unweighted Signals

In the cases where neither the GSI nor the HIC computations are possible, such as a missing component, the signal is presented as is, and qualitative evaluation of the severity may be made. This presentation, normally done in graphical form, includes the sled decelerations, the belt loads, the femur loads and any other acceleration signal which has escaped the weighted-impulse analyses.

5.5 Film Motion Analysis

High-speed photographic film coverage allows a qualitative and quantitative evaluation of the kinematics of motion of a sled test. The three dimensional motion is normally obtained with two cameras, however, additional cameras are provided as backup to cover those targets which are obstructed from view from either or both primary cameras. The configuration of the photographic coverage is diagrammed in figure 18.

5.5.1 "Digitizing" Positions

The first step in analyzing photographic data is to follow a given target on a screen. The target coordinates on the screen are recorded as well as the frame number. The coordinates are in "screen inches," relative to a "screen reference" point. The frame number provides a time reference relative to a given frame, usually taken at the beginning of a sled pulse. With the proper conversion factors, the two spatial coordinates can be converted from screen inches to real inches, and the frame number to a time instant in milliseconds. The result is time history tables of x(t) and y(t) for as many targets as desired.

5.5.2 Time Synchronization and Calibration

In order to synchronize all four cameras, a t-zero strobe flash is made visible from all cameras. The frame number corresponding to this flash is called t_0 on all films. The calibration of the film speeds is obtained with a 1000 Hz pulse, generated by the same source, and channeled simultaneously to all cameras.

New LED's were installed in all cameras so that brighter spots on the film edges are now visible. The average film speed (frames/seconds)

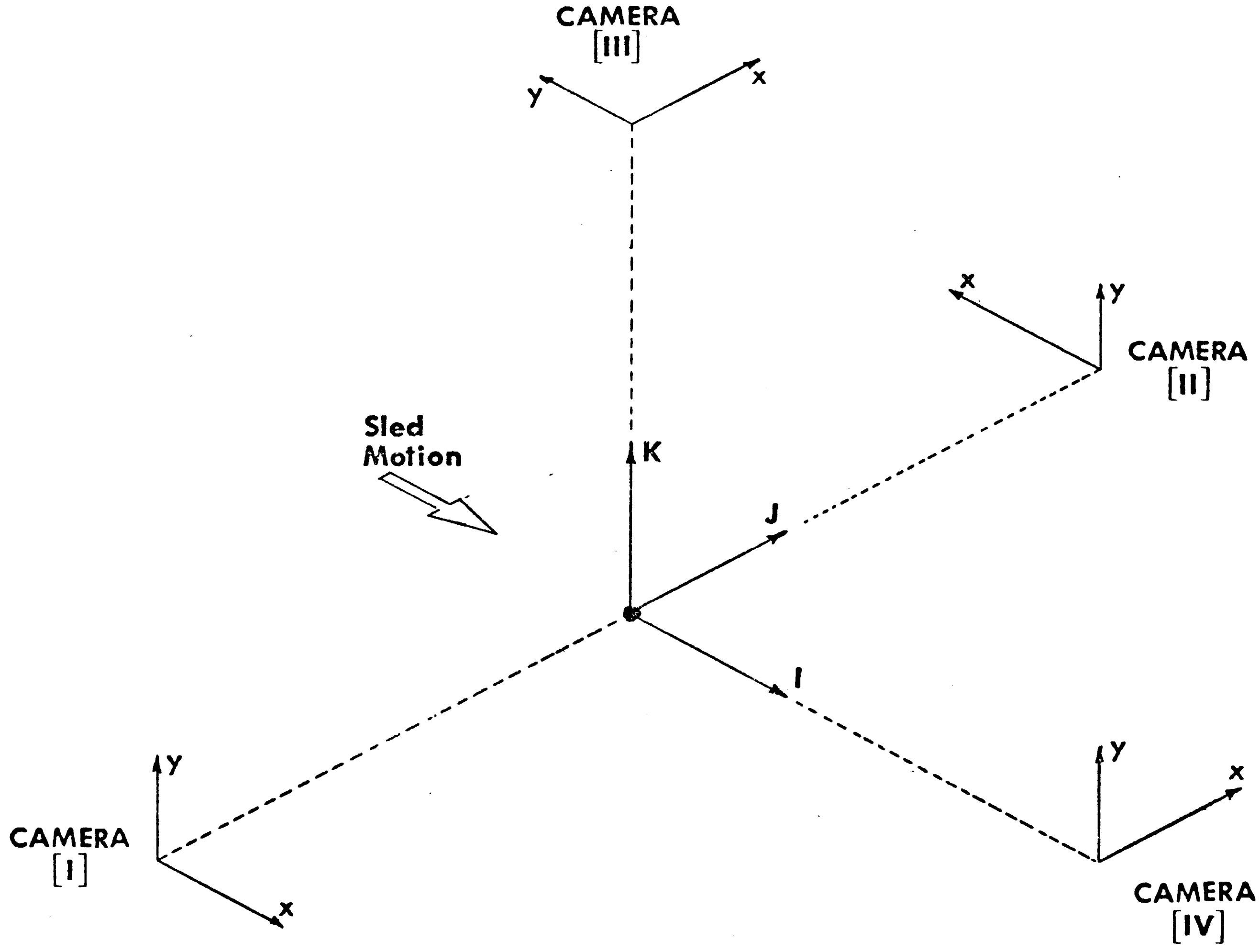


FIGURE 18. PHOTOGRAPHIC COVERAGE OF A SLED RUN

is obtained by counting the number of frames between two pulses of a given interval, usually 60-100 msec. As a backup, a rotating wheel, turning at a precise rate (1800 rpm), is installed in the field of view of camera I and III. Currently, work is under way to develop a two-flash strobe system, with the first flash at t_0 and the second flash precisely 100 msec later. Since there is small variation in film speed, and because of failures and possible error in counting light-spots, a more reliable average film speed can be obtained by counting the number of frames in the precisely indicated 100 msec interval.

5.5.3 Space Synchronization and Calibration

A new inertial reference target was designed and installed toward the later part of the second contract year. This target is more rigid than the previous one, and provides a common inertial reference point, relative to which all measurements from all films are to be computed.

The calibration of two-dimensional film analysis is more complicated than it seems to be. Although a simple calibration "gage" of known length may be used to convert screen inches to actual inches, this procedure is only approximate when the camera-target distance is small (wide-lens camera), when the target being analyzed is too far from the optical center, or when the motion of the target in-and-out of the plane of calibration is significant.

Many schemes have been suggested, however, at present time no program has been written to introduce the necessary corrections to the readings. Meanwhile, all the test films up to the end of the second contract year (WBR-6) have been "digitized" and are awaiting analysis.

5.5.4 Time Histories

The targets which were analysed for each of the 4 views of each test, vary depending on their visibility. Since ultimately one would end with x(t), y(t), z(t), many of the analysis is redundant and is used to average out reading errors. For most of the runs, the following targets were analyzed:

1. inertial target
2. sled target
3. head target (right ear)
4. head target (left ear)
5. head target (top/back of head)
6. shoulder targets (left and right)
7. thorax
8. pelvis
9. thigh

The orientation of some body segments were also directly measured. These include the thigh, the thoracic instrumentation cluster and the shoulder-to-shoulder angle.

6.0 RECOMMENDATIONS

6.1 Accelerometer Mounts

The thoracic accelerometer mount attached to T_7 is prone to damage in a test since it attaches to the rather fragile spinal process. Although not necessary, an improved design mounting directly to the vertebral body would be desirable.

6.2 Targeting

The femur lag bolts are occasionally struck by the arms and bent during rebound. To reduce this problem, a curved photo target disc conforming to the leg contours should be used in conjunction with installing the lag bolts so the heads are flush with the skin.

The spherical targets used for the head accelerometers can be improved by the addition of a screw type fastening method to attach them to the accelerometer mounting blocks rather than taping them in place.

The suspended Newtonian reference target should be rigidly mounted and consistently located to facilitate film analysis. Tethering the cadavers' hands to prevent them from striking the Newtonian reference has been successful and should be continued.

6.3 X-Rays

The quality of the lateral pelvic x-rays varies considerably between different cadavers depending on their bone composition and fluid mass, and typically lacks the desired definition. To improve the available contrast, the use of a 8:1 criss-cross x-ray grid rather than the presently available 8:1 linear grid would reduce x-ray scatter substantially as well as allow exposures of 20% higher potential. Also, to allow more accurate reconstruction of the entire skeletal structure from the x-rays, it is recommended that a permanent lead gridwork be constructed and installed on the x-ray table surface for scaling and overlay purposes. See Section 4.1.6 for a more thorough discussion of the x-ray grid.

To assist in the identification of the accelerometer positions, Q_1, Q_2 and Q_3 on the head x-rays, the marker pellets will be labeled with the appropriate lead number 1, 2, or 3 for future tests.

APPENDIX A

CADAVER DATA PRESENTATION

APPENDIX A: CADAVER DATA PRESENTATION

The dimensional and instrumentation records for the Whole Body Response series are presented in this section by test number. Cadaver tests WBR-3 through WBR-6 conducted in this contract year are included in this summary. The data for each cadaver test is reported in the following sequence:

SLED TEST SUMMARY

POSITIONING AND TARGETING DIAGRAM

BELT LENGTH AND ANCHOR GEOMETRY DATA

INSTRUMENTATION DATA SHEETS

X-RAY DATA SHEET

ANTHROPOMETRY

AUTOPSY INFORMATION

COMPUTER DATA PLOTS AND KEYS

SET-UP PHOTOS (RIGHT, FRONT, LEFT)

GRAPH-CHECK PHOTO OF TEST

POST TEST PHOTOS (If Any)

HEAD X-RAYS

WHOLE BODY X-RAYS (LATERAL)

WHOLE BODY X-RAYS (PRONE)

WHOLE BODY RESPONSE

TEST SUMMARY

TEST SERIES WBR-3

TESTS A-865 and A-866

WHOLE BODY RESPONSE

SLED TEST SUMMARY

WBR# 3 DATE 4-11-75

SLED TEST NOS. A- 865 AND A- 866

TEST SUBJECT DATA

CADAVER ID NO.: 20150 LUNGS PRESSURIZED: No

AGE: 59 years WEIGHT: 126 lbs.

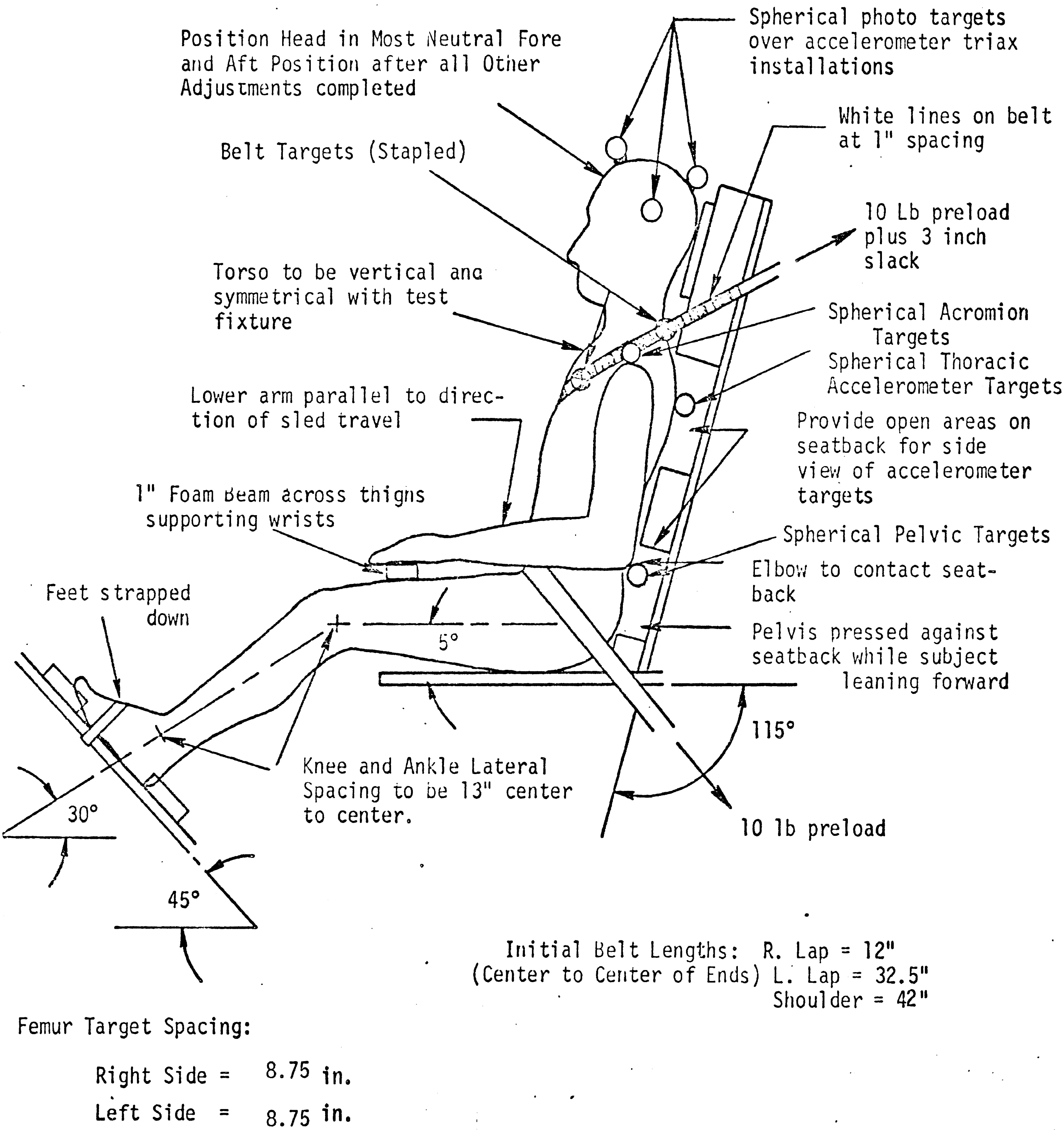
HEIGHT 173.8 cm SEX: M

TEST PARAMETERS

	FIRST IMPACT	SECOND IMPACT
VELOCITY:	22.2 MPH	31.2 MPH
DECELERATION:	8.2 G's	45.8 G's
IMPACT DIRECTION:	FRONTAL	FRONTAL
RESTRAINT SYSTEM:	3 pt. belt	3 pt. belt

POST IMPACT EVALUATION

	FIRST IMPACT	SECOND IMPACT
a. Test Subject:		
Any Injury	None obvious	Bleeding from L.R. Femur Incision
Submarining	None	None
b. Restraint System Damage:	Severe Rebound None	Shoulder Belt Slipped approx. 1" through buckle (abrasion)
c. Transducers:		
Any Units Damaged	None	None
Any Units Loosened	None	None
d. Any Data Lost:	None	None



POSITIONING AND TARGETING DIAGRAM WBR-3

WHOLE BODY RESPONSE WBR# 3

BELT LENGTH DATA

TEST A- 865

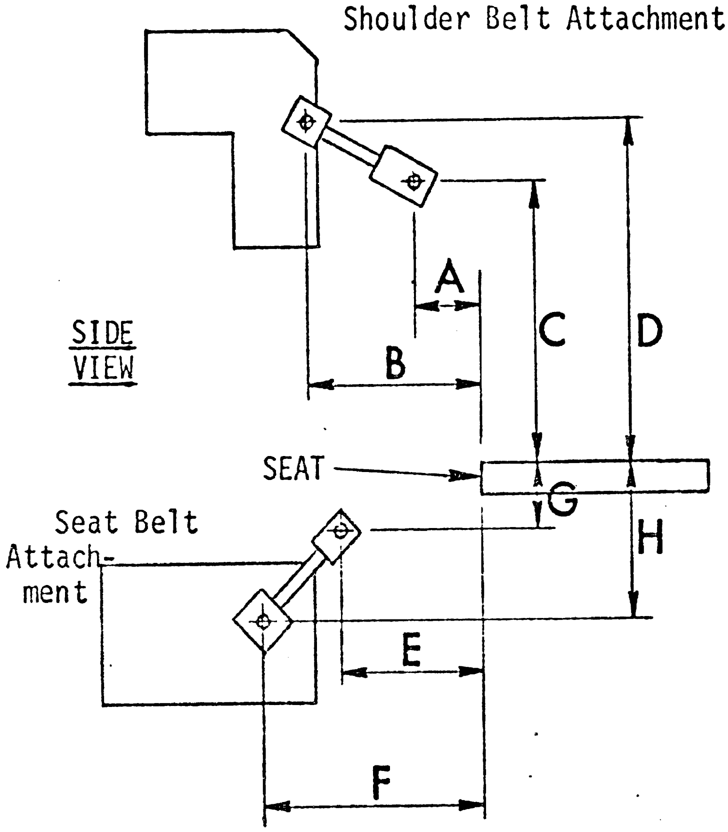
Belt Position	Pre-Impact Length (in)	Post-Impact Length (in)	Belt Stretch (in)	Post-Impact Length with Load Cells
Rt. Lap	12	12	0	11 1/4
Lt. Lap	32 1/2	32 3/4	1/4	32
Shoulder	42	42	0	40 1/4

Test A- 866

Belt Position	Pre-Impact Length (in)	Post-Impact Length (in)	Belt Stretch (in)	Post-Impact Length with Load Cells
Rt. Lap	12	12 1/8	1/8	11 1/2
Lt. Lap	32 1/2	32 5/8	1/8	32
Shoulder	42	42 3/4	3/4	41 3/8

BELT ANCHOR DATA

WBR-3
TEST A-865



SIDE VIEW

SEAT BELT DIMENSIONS

	RIGHT SIDE		LEFT SIDE
E =	3 3/4"	E =	4 3/4"
F =	7 "	F =	7 "
G =	5 7/8"	G =	8 1/2"
H =	11 1/2"	H =	11 1/2"

Belt Anchor Separations

L = 15"

M = 14 7/8"

SHOULDER BELT DIMENSIONS

A = 19"

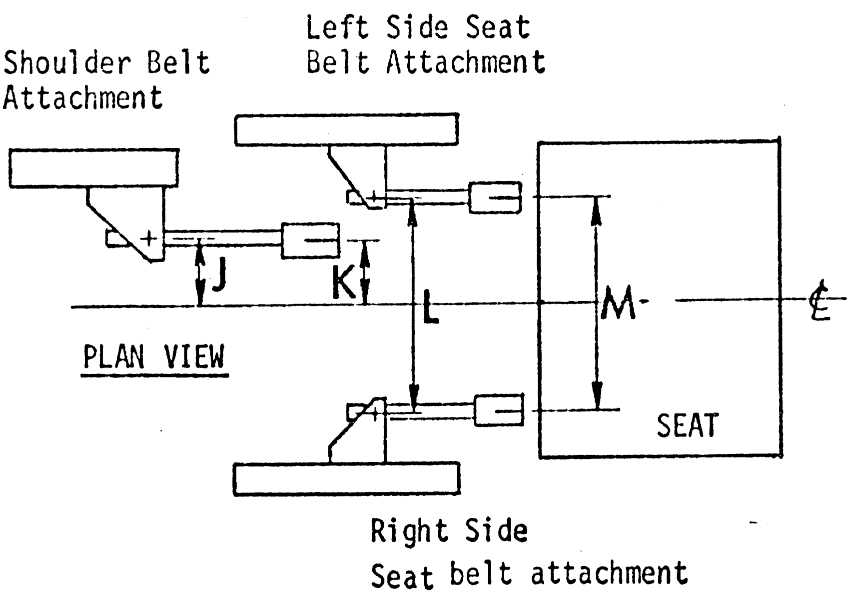
B = 23"

C = 30 1/8"

D = 31 7/8"

J = 7 1/8"

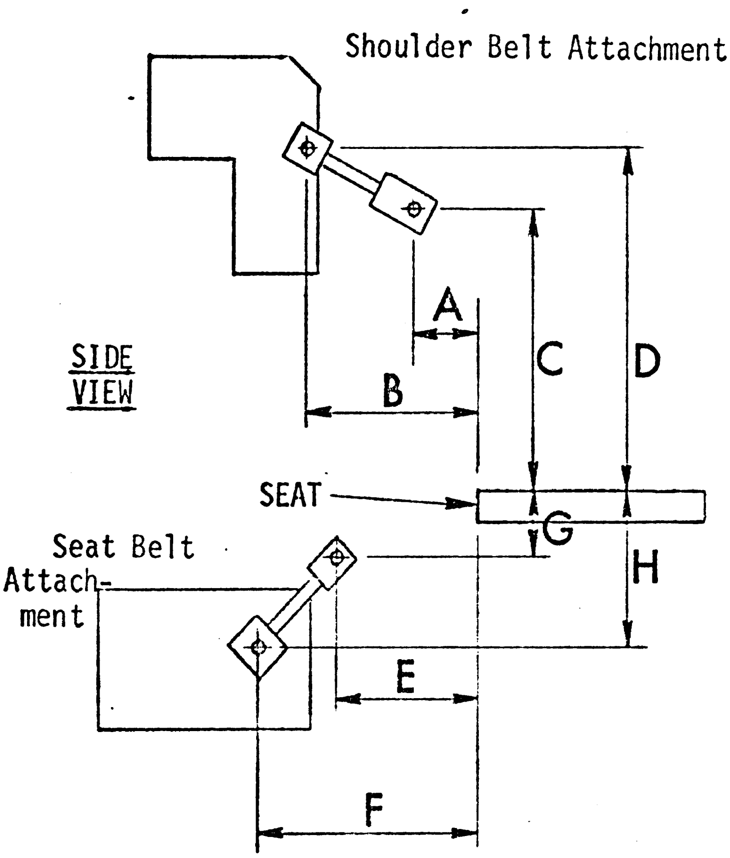
K = 6 1/8"



PLAN VIEW

BELT ANCHOR DATA

TEST WBR-3 A-866



SEAT BELT DIMENSIONS

RIGHT SIDE		LEFT SIDE	
E =	3 3/4"	E =	5"
F =	6 1/2"	F =	6 1/2"
G =	6 3/8"	G =	8"
H =	10 3/4"	H =	10 3/4"

Belt Anchor Separations

L = 14 3/4"

M = 14 3/4"

SHOULDER BELT DIMENSIONS

A = 19 3/8"

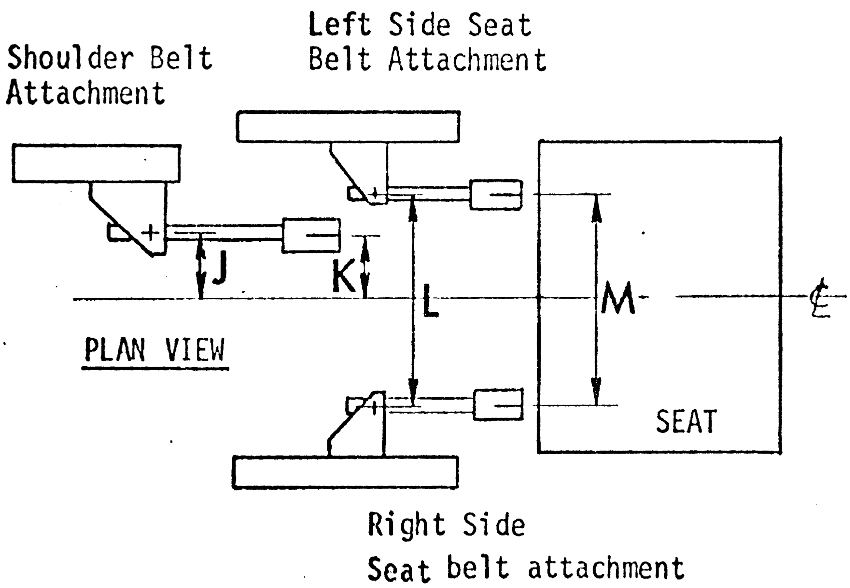
B = 23 1/4"

C = 30 5/8"

D = 32 1/8"

J = 7 1/8"

K = 6 5/8"



INSTRUMENTATION DATA SHEET

'EST NO. WBR-3 SLED RUN NO. A-865; A-866 DATE 4-11-75 PREPARED BY

'APE DATA: RECORDER Honeywell RECORD SPEED 30 IPS

	TAPE			TRANSDUCER			CALIBRATION						
CHAN.	INPUT	40% (3V) MODULATION VALUE	RUN GAIN	EXCIT. VOLT.	TYPE	S/N	CAL. RESISTOR	CAL. VOLTAGE	CAL. GAIN	CAL. VALUE	±	OUTPUT RUN SENSITIVITY	CHAN.
1	Sled Decel.		200		Stath	13587					+	20 G/V	1
2	Head Q- 1A	143.4G	100	10	Endev	AA-06	199.4K	1.184	100	56.5G	+	47.8 G/V	2
3	Head Q- 1B	125.1G	100	10	"	AA-17	199.4K	1.437	100	59.9G	-	41.7 G/V	3
4	Head Q- 1C	121.2G	100	10	"	AA-16	199.4K	1.173	100	47.4G	-	40.4 G/V	4
5	Head Q- 2C	128.4G	100	10	"	AA-26	199.4K	1.174	100	50.3G	-	42.8 G/V	5
6	Head Q- 2A	118.5G	100	10	"	AA-30	199.4K	1.156	100	45.7G	-	39.5 G/V	6
7	Head Q- 2B	138.3G	100	10	"	AA-36	199.5K	1.163	100	53.6G	+	46.1 G/V	7
8	Head Q- 3B	141.3G	100	10	"	AA-50	199.5K	1.175	100	55.3G	-	47.1 G/V	8
9	Head Q- 3C	134.7G	100	10	"	AA-65	199.5K	1.153	100	51.8G	-	44.9 G/V	9
10	Head Q- 3A	144.6G	100	10	"	AA-66	199.5K	1.174	100	56.6G	-	48.2 G/V	10
11													11
12	Velocity Pulse											12"/Pulse	12
13													13
14	Time Base											.01 sec/ pulse	14

INSTRUMENTATION DATA SHEET

TEST NO. WBR-3 SLED RUN NO. A-865; A-866 DATE 4-11-75 PREPARED BY

TAPE DATA: RECORDER CEC : RECORD SPEED 30 IPS

		TAPE		TRANSDUCER			CALIBRATION						
CHAN.	INPUT	40% (3V) MODULATION VALUE	RUN GAIN	EXCIT. VOLT.	TYPE	S/N	CAL. RESISTOR	CAL. VOLTAGE	CAL. GAIN	CAL. VALUE	+ -	OUTPUT RUN SENSITIVITY	CHAN.
1	Sled Decel.		200		Stath	13587					+	20 G/V	1
2	Pelvis A-P	158.1 G	100	10	Entrn	34X	102.3K	.835	100	44.0G		52.7 G/V	2
3	Pelvis S-I	150.0 G	100	10	"	34Y	102.3K	.843	100	43.0G		51.0 G/V	3
4	Thorax A-P	185.7 G	100	10	"	134Y	102.3K	.869	100	53.8G		61.9 G/V	4
5	Thorax S-I	180.9 G	100	10	"	134X	102.3K	.892	100	53.8G		60.3 G/V	5
6	Thorax L-R	152.7 G	100	10	"	910X	102.5K	1.235	100	62.9G		50.9 G/V	6
7	Rt. Lap	2893.8#	200	-	G.S.E	082	50 K	2.29		2209#	+	964.6 #/V	7
8	Lt. Lap	3002.7#	200	-	"	083	50 K	2.24		2242#	+	1000.9 #/V	8
9	Up. Snldr.	3090.9#	VAR	-	"	084	50 K	2.21		2277#	+	1030.3 #/V	9
10	Low Snldr.	2476.2#	VAR	-	"	085	50 K	2.72		2245#	+	825.4 #/V	10
11													11
12	Velocity											12"/Pulse	12
13													13
14	Time Base											.01 Sec/ pulse	14

HEAD X-RAY DATA SHEET

WHOLE BODY RESPONSE PROJECT

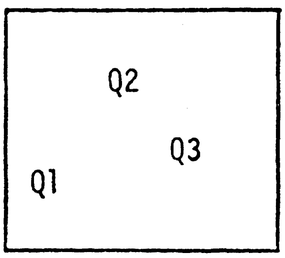
WBR NO. 3

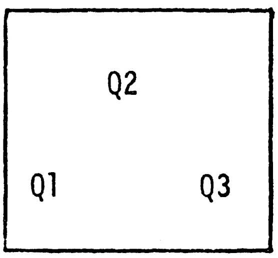
TARGET		INSTALLATION FIXTURE DIMENSION	DISTANCE FROM X-RAY PLANE X-Z PLANE (Side view)	Y-Z PLANE (Frontal)
ACCELEROMETERS				
Location	Name			
ollet Furthest to ight-Rear of Head	Q_1	5.38	14.0	12.25
ext Collet clockwise rom Q_1 (viewed from top)	Q_2	4.81	10.0	12.25
ext Collet clockwise rom Q_2 (viewed from top)	Q_3	4.48	12.75	16.0

ANATOMICAL MARKER PELLETS		X-Z PLANE (Side view)	Y-Z PLANE (Frontal)
Right Eye	□	12.0	19
Left Eye	□ with stem	9.5	18.75
Right Ear	○	14.5	16.75
Left Ear	○ with stem	8.5	16

X-RAY DATA	X-Z PLANE (Side view)	Y-Z PLANE (Frontal)
VOLTAGE	136	136
CURRENT	100	100
TIME	0.5	0.5
SATISFACTORY? (Check if Yes)	✓	✓

Sketch of Relative Positions of Accelerometer Targets As Viewed from X-Ray Source.





WHOLE BODY RESPONSE: ANTHROPOMETRY

CADAVER ID: 20150

DATE: 4-16-75

ANTHROPOMETRIST: H. M. Reynolds

Anthropometric Measurements:

(A = Anthropometer; Sp. C. = Spreading Calipers; Sl. C. = sliding calipers; T = Tapes)

1.	Weight		126 lbs
2.	Stature (A)		173.8 cm
3.	Trochanterion Hgt. (A)	Rt.	85.9
		Lt.	86.0
4.	Anterior-Superior Iliac Spine Hgt. (A)	Rt.	79.9
		Lt.	79.9
5.	Iliocristale Hgt. (A)	Rt.	69.9
		Lt.	71.7
6.	Substernale Hgt. (A)		58.8
7.	Axilla Hgt. (A)		48.9
8.	Suprasternale Hgt. (A)		37.0
9.	Nipple Hgt. (A)		
10.	Mastoid Hgt. (A)		15.9
11.	Nuchale Hgt. (A)		
12.	Tragion Hgt. (A)	Rt.	11.7
		Lt.	12.0
13.	Menton Hgt. (A)		
14.	Head Breadth (Sp. C.)		15.5
15.	Head Length (Sp. C.)		19.6

Cad. I.D. 20150

16.	Bitragion Diameter (Sp. C.)	14.0
17.	Bigonial Diameter (Sp. C.)	11.0
18.	Menton Diagonal (Sp. C.)	
19.	Mastoid Diagonal (A)	
20.	Head Circumference (T)	57.3
21.	Mid-Sagittal Arc Length (T)	35.7
22.	Coronal Arc Length (T)	33.3
23.	Mid-Neck Circumference (T)	
24.	Chest Circumference at Axilla (T)	
25.	Chest Circumference at Nipple (T)	
26.	Chest Circumference at Substernale (T)	
27.	Hip Circumference, Iliocristale (T)	78.6
28.	Buttocks Circumference, Trochanterion (T)	87.1
29.	Upper Arm Circumference, Axilla (T)	27.1
30.	Upper Arm Circumference, Mid Biceps (T)	24.3
31.	Upper Arm Circumference, Humeral Condyles (T)	23.6
32.	Maximum Forearm Circumference (T)	24.0
33.	Wrist Circumference (T)	16.5
34.	Upper Thigh Circumference (T)	43.7
35.	Mid-Thigh Circumference (T)	37.0
36.	Lower Thigh Circumference (T)	31.5
37.	Maximum Calf Circumference (T)	28.7
38.	Ankle Circumference (T)	18.5

Cad. I.D. 20150

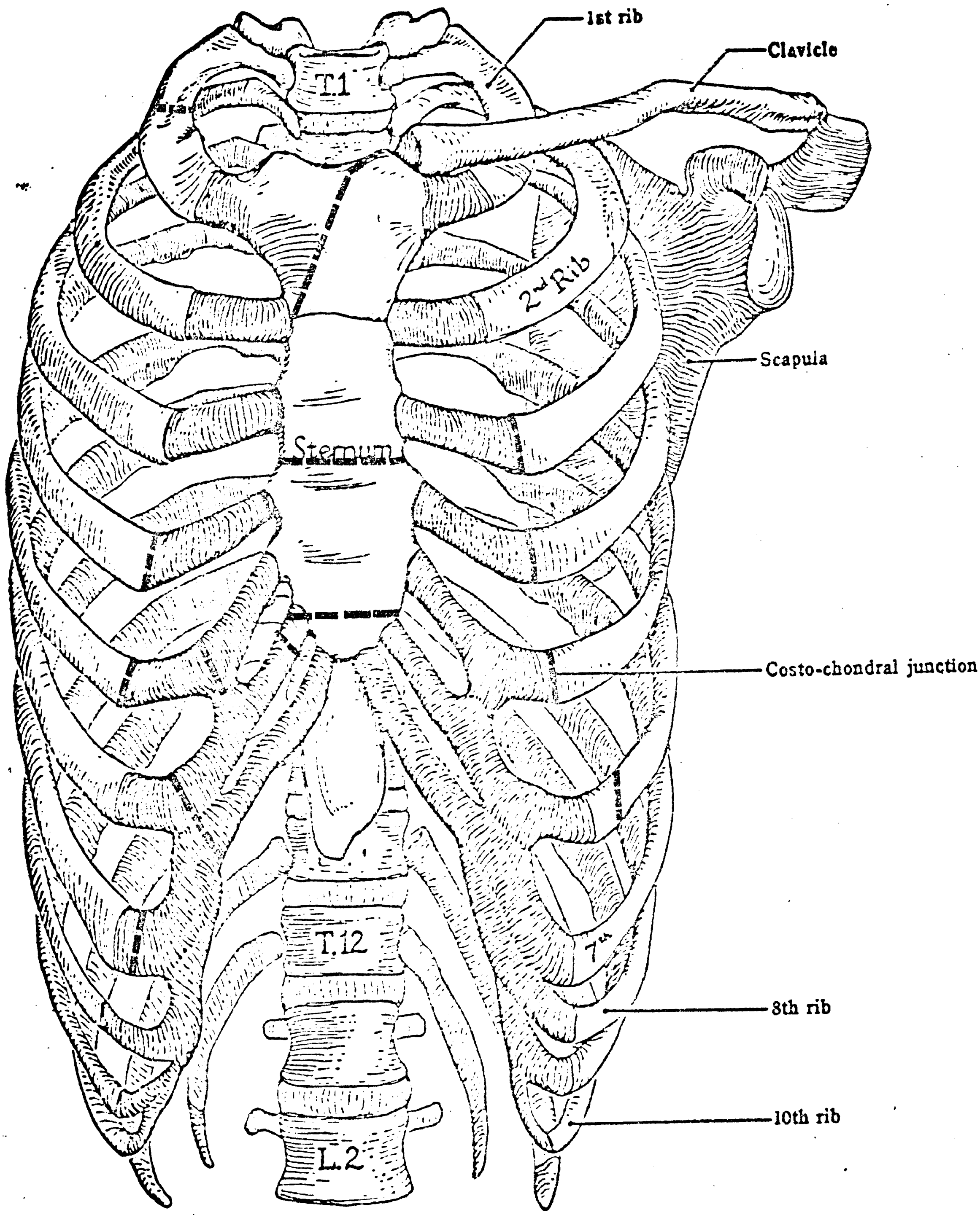
39.	Biacromial Diameter (A)		35.4
40.	Bideltoid Breadth (A)		41.0
41.	Chest Breadth at Axilla (A)		30.3
42.	Chest Breadth at Mid-Point between Suprasternale and Substernale		29.3
43.	Chest Breadth at Substernale (A)		29.3
44.	Hip Breadth, Iliocristale (A)		27.6
45.	Bispinous Diameter (A)		23.4
46.	ASIS to Symphysion Distance (A)	Rt.	12.7
		Lt.	13.7
47.	Bitrochanteric Diameter (A)		27.3
48.	Chest Depth at Suprasternale (A)		17.6
49.	Chest Depth at Axilla (A)		18.1
50.	Chest Depth at Nipple (A)		
51.	Chest Depth at Substernale (A)		20.2
52.	Hip Depth, Iliocristale (A)		18.8
53.	ASIS Depth (A)	Rt.	18.2
		Lt.	16.2
54.	Buttocks Depth, Trochanterion (A)		19.7
55.	Trochanterion	Rt.	
		Lt.	
56.	Symphysion (Hgt.)		
57.	Acromion-Radiale Length		32.8

Cad. I.D. 20150

58. Ball of Humerus - Radiale Length (A)	30.3
59. Radiale-Stylion Length (A)	24.3
60. Olecronan-Stylion Length (A)	26.9
61. Femur Length (A)	42.1
62. Tibia Length (A)	37.3
63. Fibula Length (A)	38.2
64. Upper Arm Depth, Mid Biceps (Sl.C.)	8.6
65. Humeral Biepicondylar Breadth (Sl.C.)	7.3
66. Forearm Depth (Sl.C.)	7.3
67. Wrist Depth (Sl.C.)	6.1
68. Hand Length (Sl.C.)	17.5
69. Hand Breadth (Sl.C.)	7.9
70. Hand Depth (Sl.C.)	2.5
71. Thigh Breadth, Mid-Thigh (Sl.C,)	13.1
72. Calf Depth (Sl.C.)	9.2
73. Bimalleolus Breadth (Sl. C.)	6.9
74. Foot Length (Sl.C.)	24.3
75. Foot Breadth (Sl.C.)	8.7

WHOLE BODY RESPONSE - WBR #3

AUTOPSY RESULTS



Bony Thorax, anterior aspect

RIB FRACTURE SITES ARE INDICATED BY DASHED LINES (------)

OTHER INJURIES:

A large bruise on the left side shoulder over the clavicle. This bruise was extensive into the muscle about A 1/4 to 1/2 inch deep. Several areas were noted where Pneumothorax had occurred. One was located on the right side at the fracture on R5. Another Pneumothorax occurred on the left side at R5 and a third pneumothorax on the left side at R6. The rib

WHOLE BODY RESPONSE - WBR #3 AUTOPSY RESULTS (continued)

fractures are noted on the autopsy sheet. There was some bruising of the heart but we were not able to tell whether this was caused by belt loading or had occurred prior to death, since the individual died of heart attack.

TAPE: GMR-F1

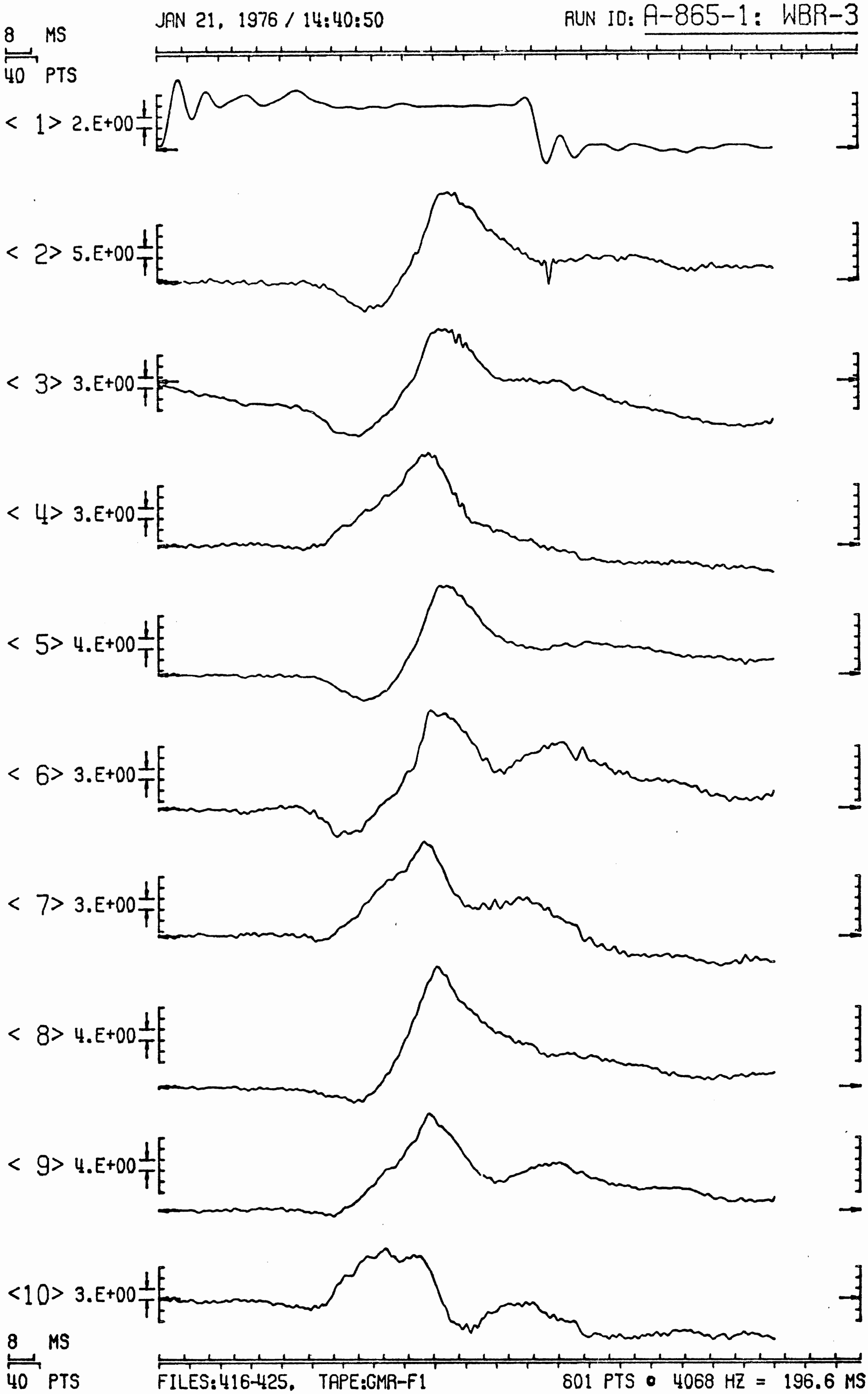
DIGITAL SIGNAL FILTERING
JAN 21, 1976 03:12:07

RUN ID: A-865-1: WBR-3

PROJECT: WHOLE BODY RESPONSE: CADAVER WBR-3 (9-ACC)

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
416 -	1:	SLED DECELERATION	G'S	801	4068.	LP(015-045)	(1)
417 -	2:	AX1 HEAD ACC (A)	G'S	801	4068.	LP(090-180)	(3)
418 -	3:	AY1 HEAD ACC (B)	G'S	801	4068.	LP(090-180)	(3)
419 -	4:	AZ1 HEAD ACC (C)	G'S	801	4068.	LP(090-180)	(3)
420 -	5:	AX2 HEAD ACC (C)	G'S	801	4068.	LP(090-180)	(3)
421 -	6:	AY2 HEAD ACC (A)	G'S	801	4068.	LP(090-180)	(3)
422 -	7:	AZ2 HEAD ACC (B)	G'S	801	4068.	LP(090-180)	(3)
423 -	8:	AX3 HEAD ACC (B)	G'S	801	4068.	LP(090-180)	(3)
424 -	9:	AY3 HEAD ACC (C)	G'S	801	4068.	LP(090-180)	(3)
425 -	10:	AZ3 HEAD ACC (A)	G'S	801	4068.	LP(090-180)	(3)
	11:						
	12:						

FILES: 416 - 425 ON TAPE: GMR-F1 RUN: A-865-1: WBR-3 FILTERED JAN 21, 1976 03:12:40


JAN 21, 1976 / 14:40:50
RUN ID: A-865-1: WBR-3
8 MS
40 PTS
< 1> 2.E+00
< 2> 5.E+00
< 3> 3.E+00
< 4> 3.E+00
< 5> 4.E+00
< 6> 3.E+00
< 7> 3.E+00
< 8> 4.E+00
< 9> 4.E+00
<10> 3.E+00
8 MS
40 PTS
FILES:416-425, TAPE:GMR-F1
801 PTS @ 4068 HZ = 196.6 MS

DIGITAL SIGNAL FILTERING
JAN 21, 1976 03:26:01

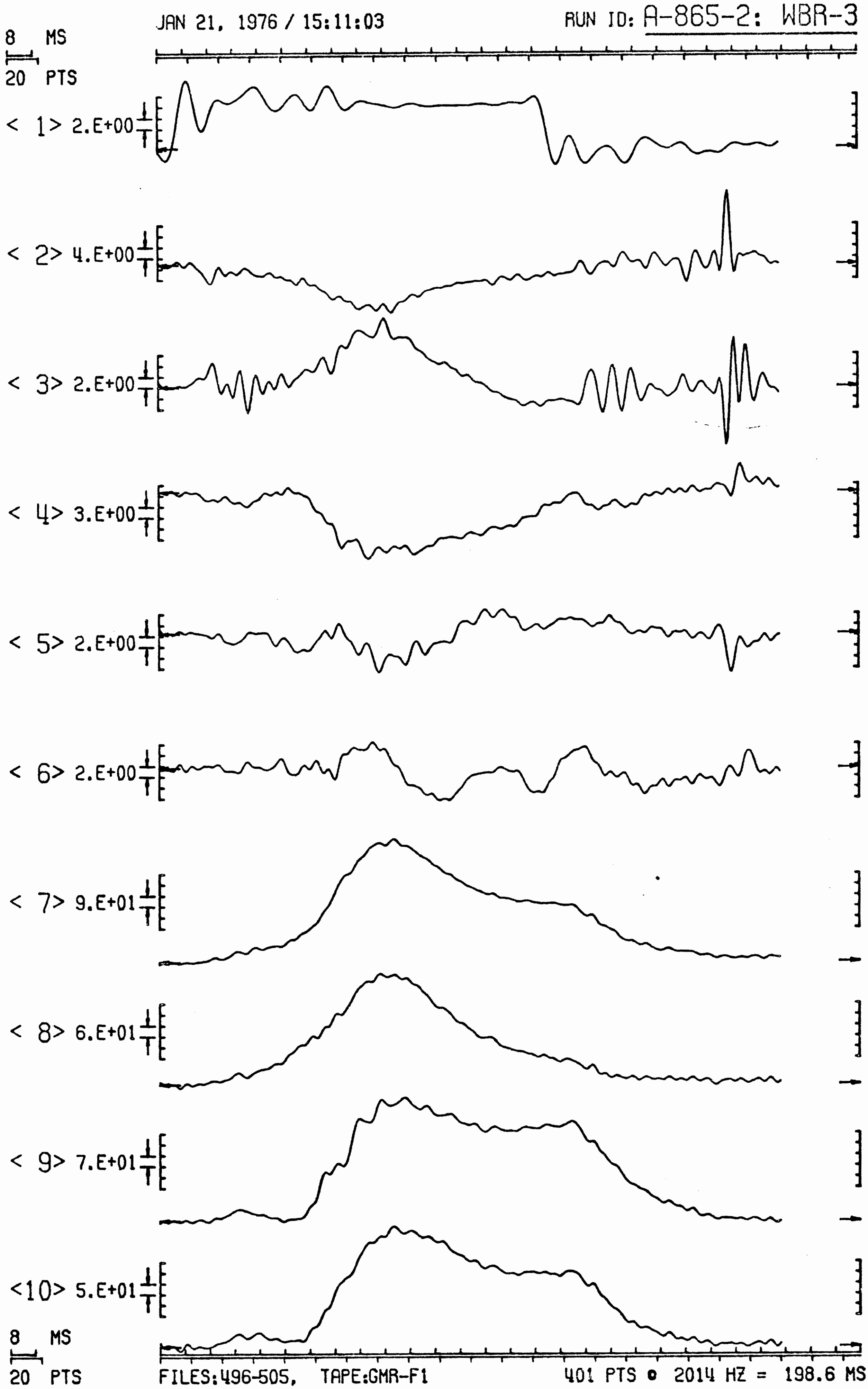
TAPE: GMR-F1

RUN ID: A-865-2: WBR-3

PROJECT: WHOLE BODY RESPONSE.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
496 -	1:	SLED DECELERATION	G'S	401	2015.	LP(030-090)	(4)
497 -	2:	PELVIS BIAX P-A ACC	G'S	401	2015.	LP(090-225)	(5)
498 -	3:	PELVIS BIAX I-S ACC	G'S	401	2015.	LP(090-225)	(5)
499 -	4:	THORAX TRIAX P-A ACC	G'S	401	2015.	LP(090-225)	(5)
500 -	5:	THORAX TRIAX I-S ACC	G'S	401	2015.	LP(090-225)	(5)
501 -	6:	THORAX TRIAX R-L ACC	G'S	401	2015.	LP(090-225)	(5)
502 -	7:	RIGHT LAP BELT LOAD	LBS	401	2015.	LP(090-225)	(5)
503 -	8:	LEFT LAP BELT LOAD	LBS	401	2015.	LP(090-225)	(5)
504 -	9:	UPPER SHOULDER BELT LOAD	LBS	401	2015.	LP(090-225)	(5)
505 -	10:	LOWER SHOULDER BELT LOAD	LBS	401	2015.	LP(090-225)	(5)
	11:						
	12:						

FILES: 496 - 505 ON TAPE: GMR-F1 RUN: A-865-2: WBR-3 FILTERED JAN 21, 1976 03:26:34



JAN 21, 1976 / 15:11:03
RUN ID: A-865-2: WBR-3
8 MS
20 PTS
< 1> 2.E+00
< 2> 4.E+00
< 3> 2.E+00
< 4> 3.E+00
< 5> 2.E+00
< 6> 2.E+00
< 7> 9.E+01
< 8> 6.E+01
< 9> 7.E+01
<10> 5.E+01
8 MS
20 PTS
FILES:496-505, TAPE:GMR-F1
401 PTS @ 2014 HZ = 198.6 MS

TAPE: GMR-F1

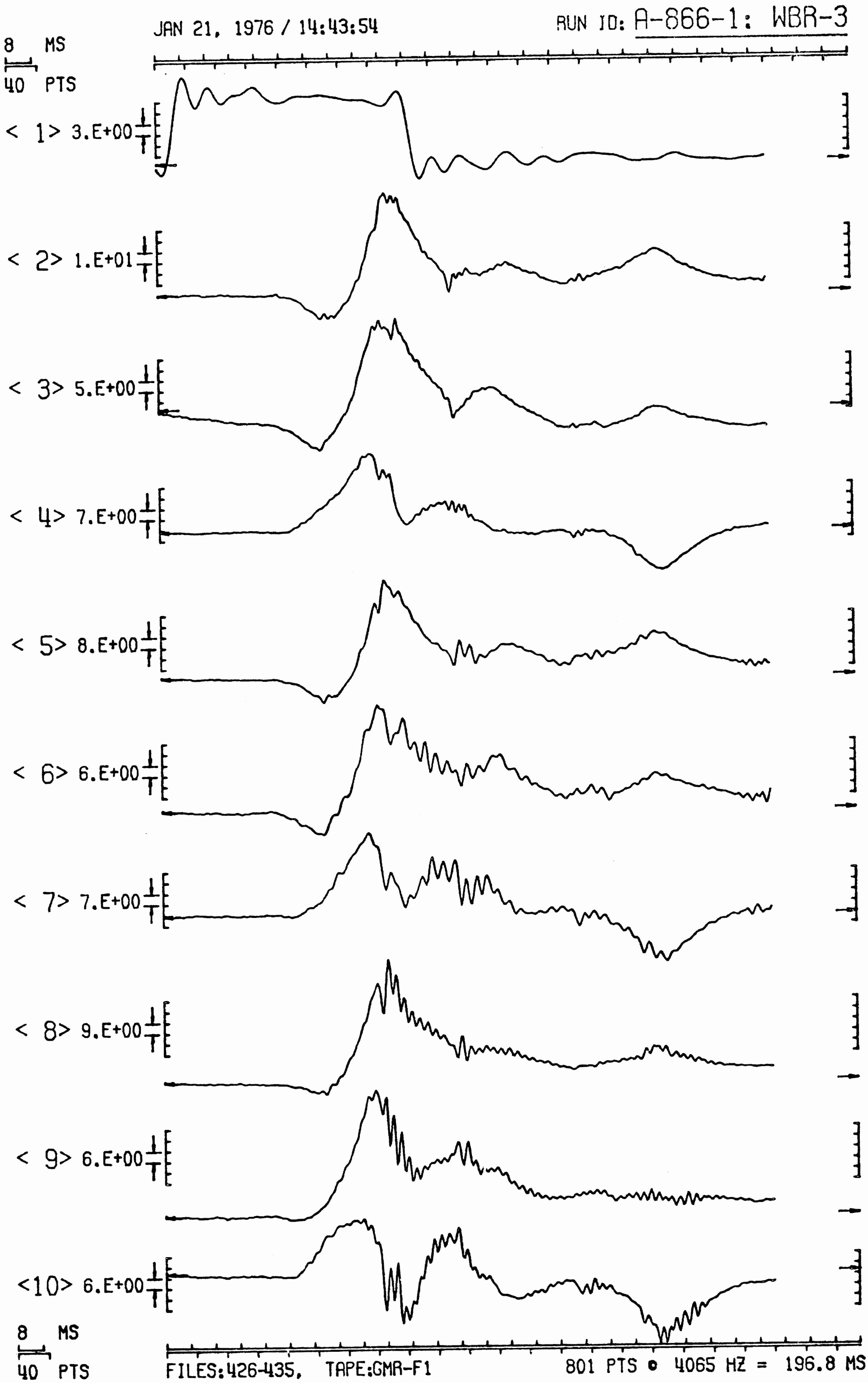
DIGITAL SIGNAL FILTERING
JAN 21, 1976 03:13:42

RUN ID: A-866-1: WBR-3

PROJECT: WHOLE BODY RESPONSE: CADAVER WBR-3 (9-ACC)

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
426 -	1:	SLED DECELERATION	G'S	801	4066.	LP(015-045)	(1)
427 -	2:	AX1 HEAD ACC (A)	G'S	801	4066.	LP(090-180)	(3)
428 -	3:	AY1 HEAD ACC (B)	G'S	801	4066.	LP(090-180)	(3)
429 -	4:	AZ1 HEAD ACC (C)	G'S	801	4066.	LP(090-180)	(3)
430 -	5:	AX2 HEAD ACC (C)	G'S	801	4066.	LP(090-180)	(3)
431 -	6:	AY2 HEAD ACC (A)	G'S	801	4066.	LP(090-180)	(3)
432 -	7:	AZ2 HEAD ACC (B)	G'S	801	4066.	LP(090-180)	(3)
433 -	8:	AX3 HEAD ACC (B)	G'S	801	4066.	LP(090-180)	(3)
434 -	9:	AY3 HEAD ACC (C)	G'S	801	4066.	LP(090-180)	(3)
435 -	10:	AZ3 HEAD ACC (A)	G'S	801	4066.	LP(090-180)	(3)
	11:						
	12:						

FILES: 426 - 435 ON TAPE: GMR-F1 RUN: A-866-1: WBR-3 FILTERED JAN 21, 1976 03:14:14


JAN 21, 1976 / 14:43:54
RUN ID: A-866-1: WBR-3
8 MS
40 PTS
< 1> 3.E+00
< 2> 1.E+01
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< 4> 7.E+00
< 5> 8.E+00
< 6> 6.E+00
< 7> 7.E+00
< 8> 9.E+00
< 9> 6.E+00
<10> 6.E+00
8 MS
40 PTS
FILES:426-435, TAPE:GMR-F1
801 PTS @ 4065 HZ = 196.8 MS

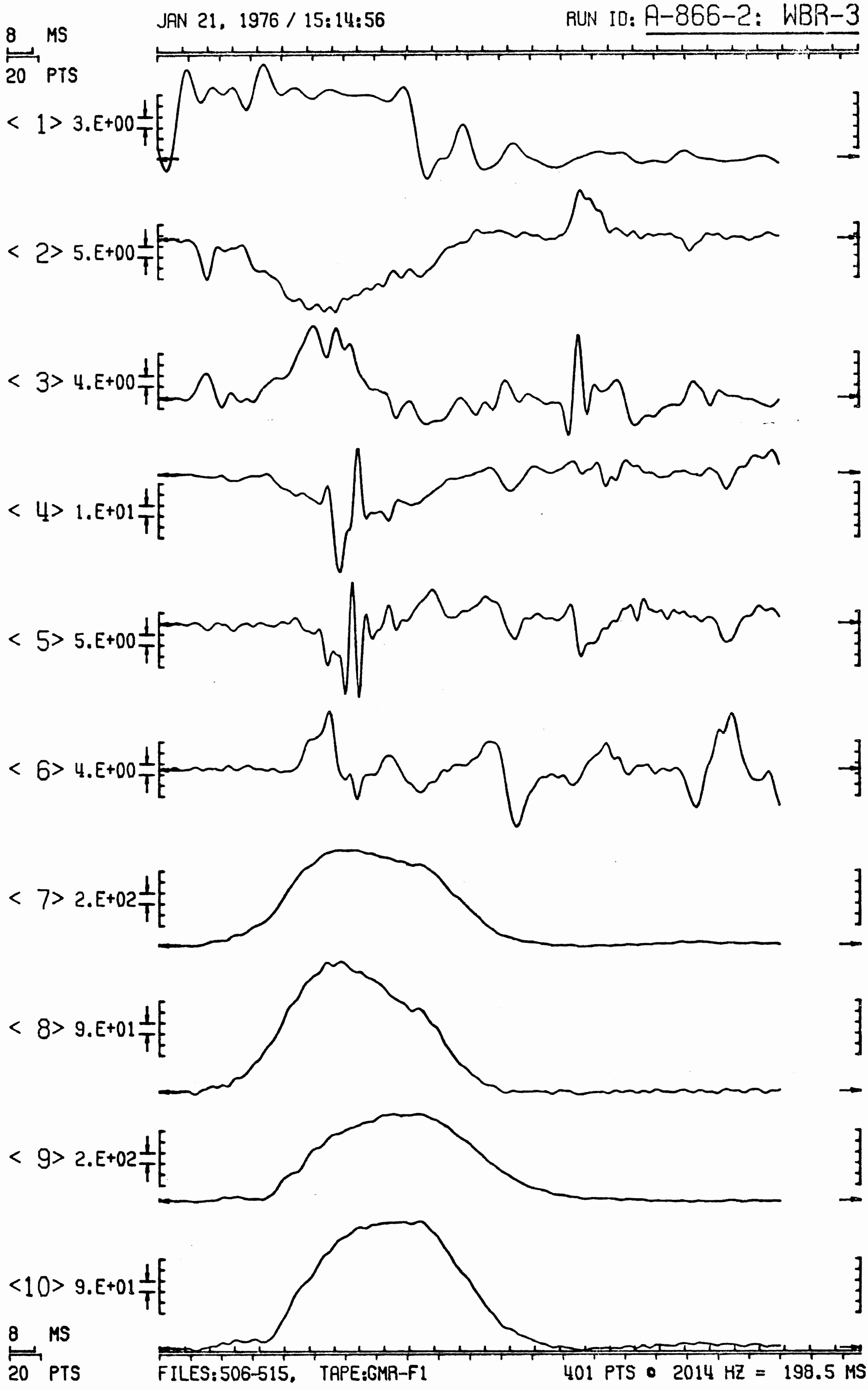
DIGITAL SIGNAL FILTERING

TAPE: GMR-F1 | JAN 21, 1976 03:27:27 | RUN ID: A-866-2: WBR-3

PROJECT: WHOLE BODY RESPONSE.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
506 -	1:	SLED DECELERATION	G'S	401	2015.	LP(030-090)	(4)
507 -	2:	PELVIS BIAX P-A ACC	G'S	401	2015.	LP(090-225)	(5)
508 -	3:	PELVIS BIAX I-S ACC	G'S	401	2015.	LP(090-225)	(5)
509 -	4:	THORAX TRIAX P-A ACC	G'S	401	2015.	LP(090-225)	(5)
510 -	5:	THORAX TRIAX I-S ACC	G'S	401	2015.	LP(090-225)	(5)
511 -	6:	THORAX TRIAX R-L ACC	G'S	401	2015.	LP(090-225)	(5)
512 -	7:	RIGHT LAP BELT LOAD	LBS	401	2015.	LP(090-225)	(5)
513 -	8:	LEFT LAP BELT LOAD	LBS	401	2015.	LP(090-225)	(5)
514 -	9:	UPPER SHOULDER BELT LOAD	LBS	401	2015.	LP(090-225)	(5)
515 -	10:	LOWER SHOULDER BELT LOAD	LBS	401	2015.	LP(090-225)	(5)
	11:						
	12:						

FILES: 506 - 515 ON TAPE: GMR-F1 RUN: A-866-2: WBR-3 FILTERED JAN 21, 1976 03:28:00


JAN 21, 1976 / 15:14:56
RUN ID: A-866-2: WBR-3
8 MS
20 PTS
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< 2> 5.E+00
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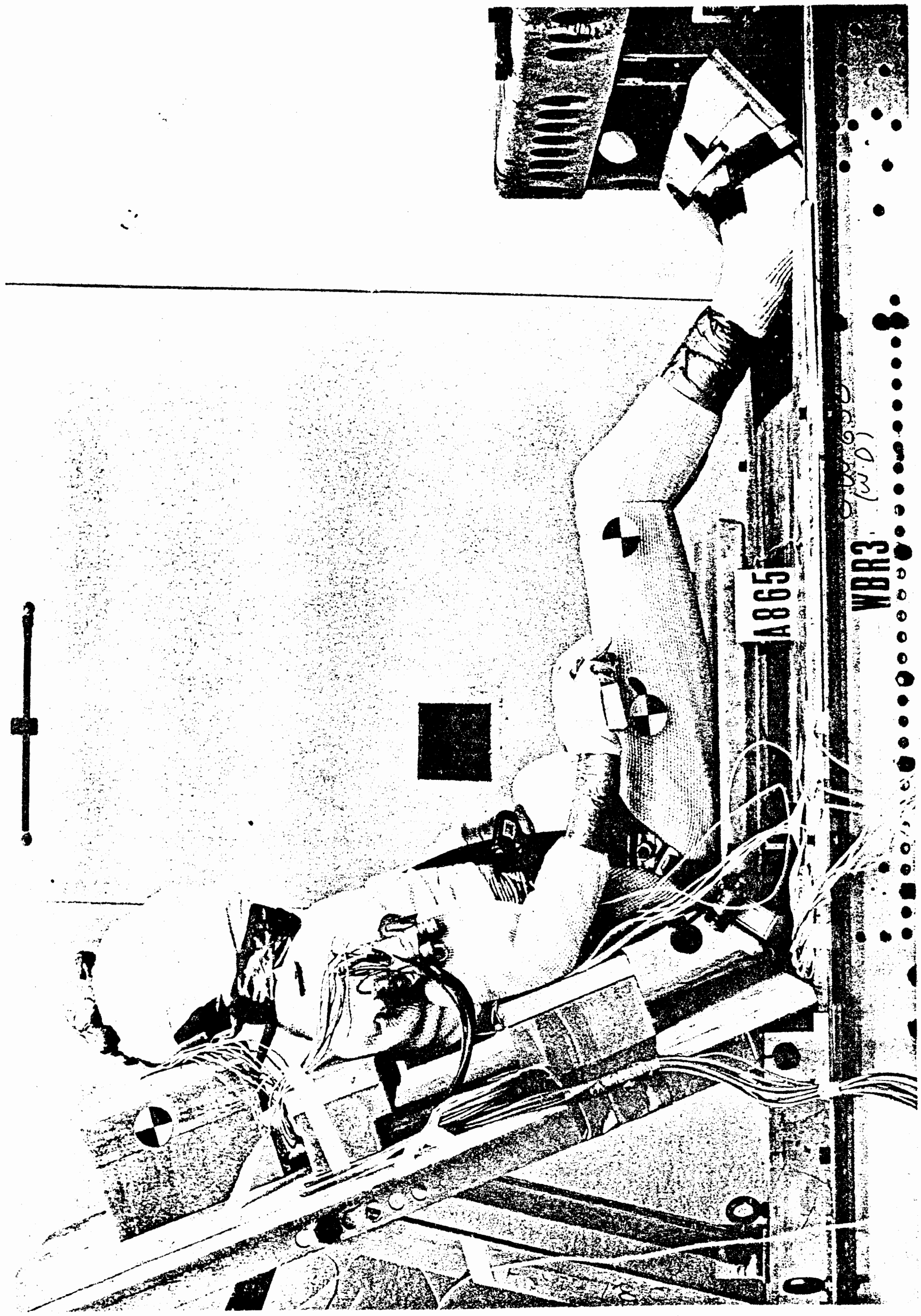
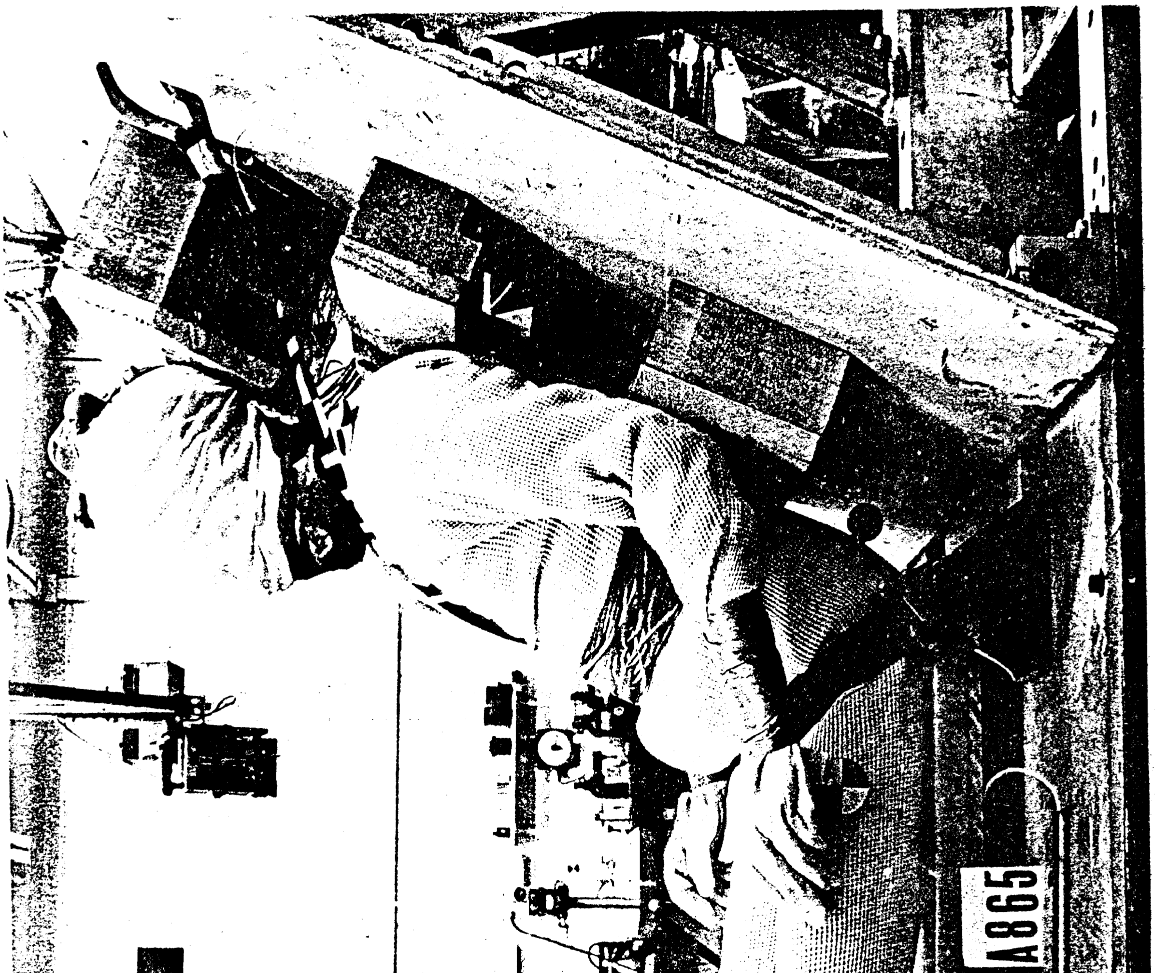
< 5> 5.E+00
< 6> 4.E+00
< 7> 2.E+02
< 8> 9.E+01
< 9> 2.E+02
<10> 9.E+01
8 MS
20 PTS
FILES:506-515, TAPE:GMR-F1
401 PTS @ 2014 HZ = 198.5 MS

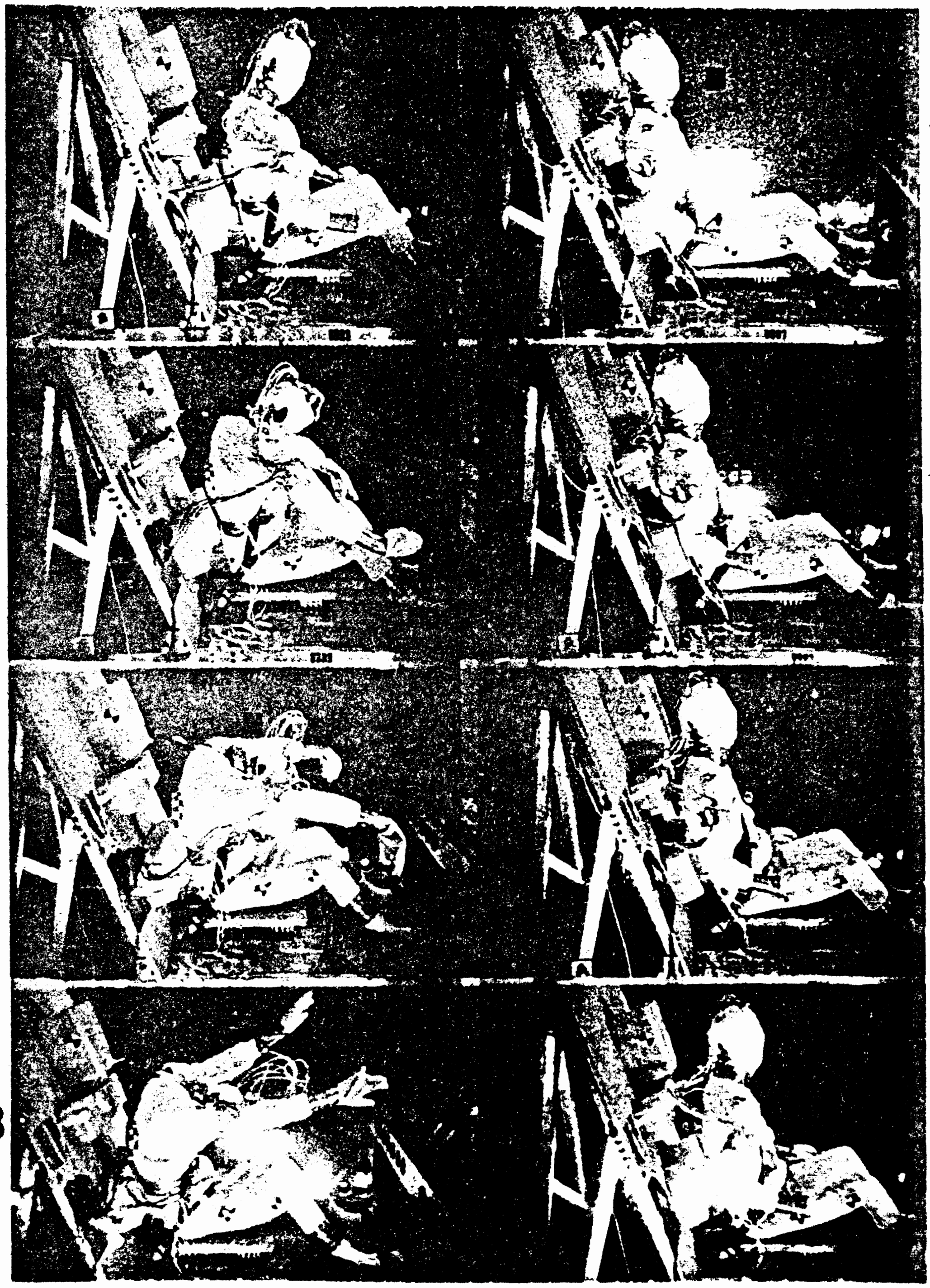


SETUP PHOTOGRAPH: TEST A-865

SETUP PHOTOGRAPH: TEST A-865

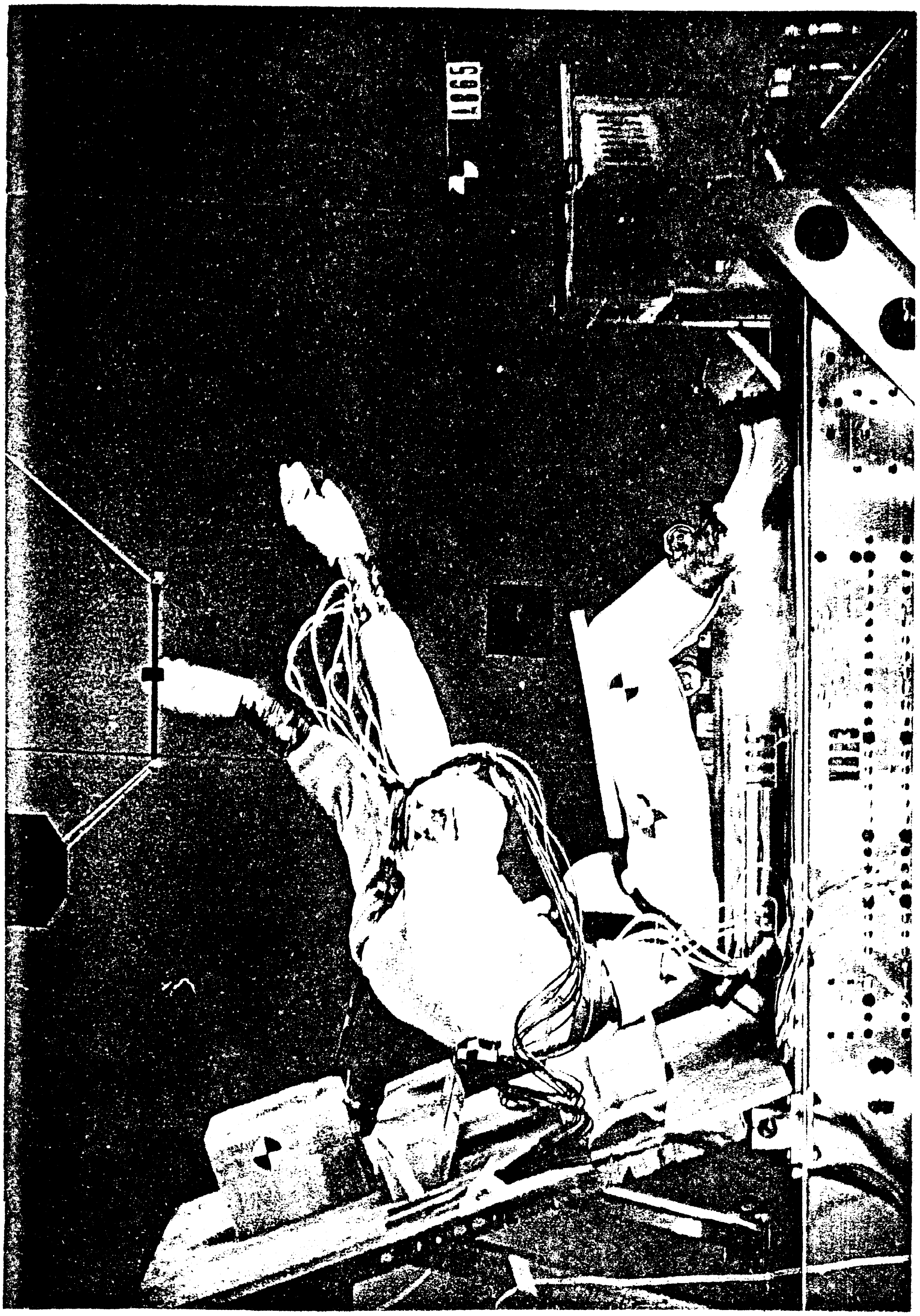


SETUP PHOTOGRAPH: TEST A-865



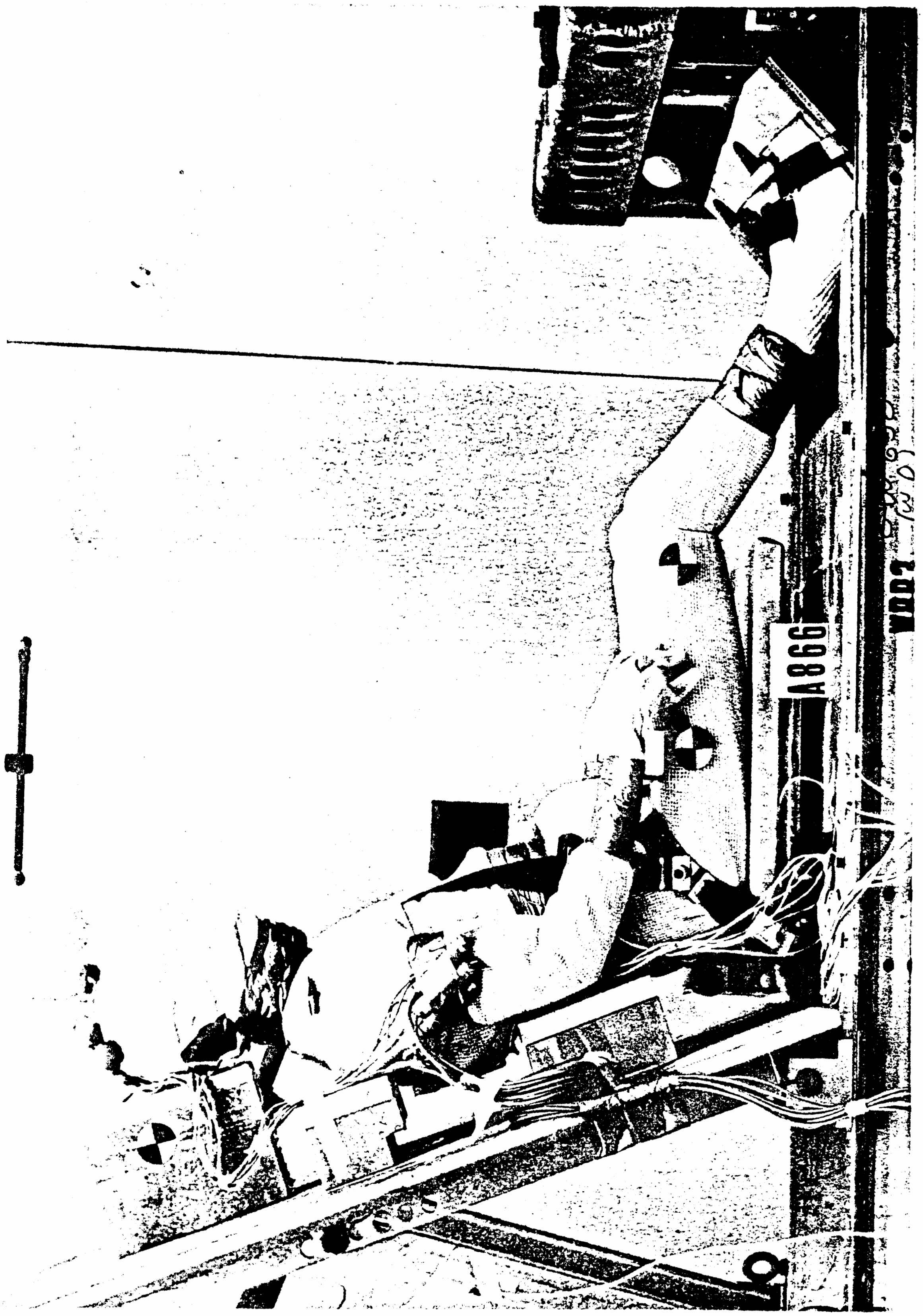
A865

GRAPHCHECK PHOTOGRAPH: TEST A-865



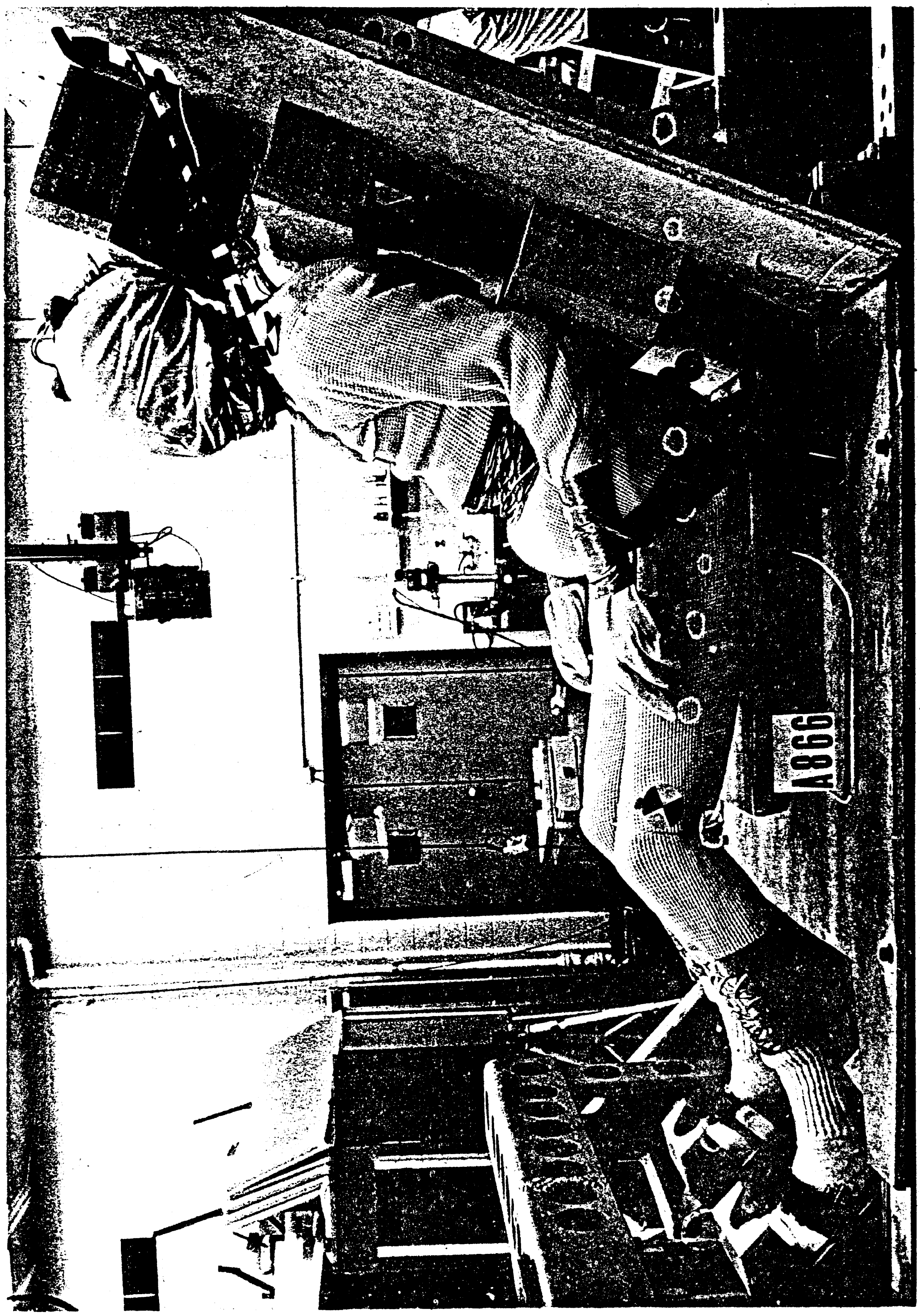
TEST PHOTOGRAPH: WBR-3, TEST A-865

POST-TEST PHOTOGRAPH: TEST A-865



SETUP PHOTOGRAPH: TEST A-866

SETUP PHOTOGRAPH: TEST A-866



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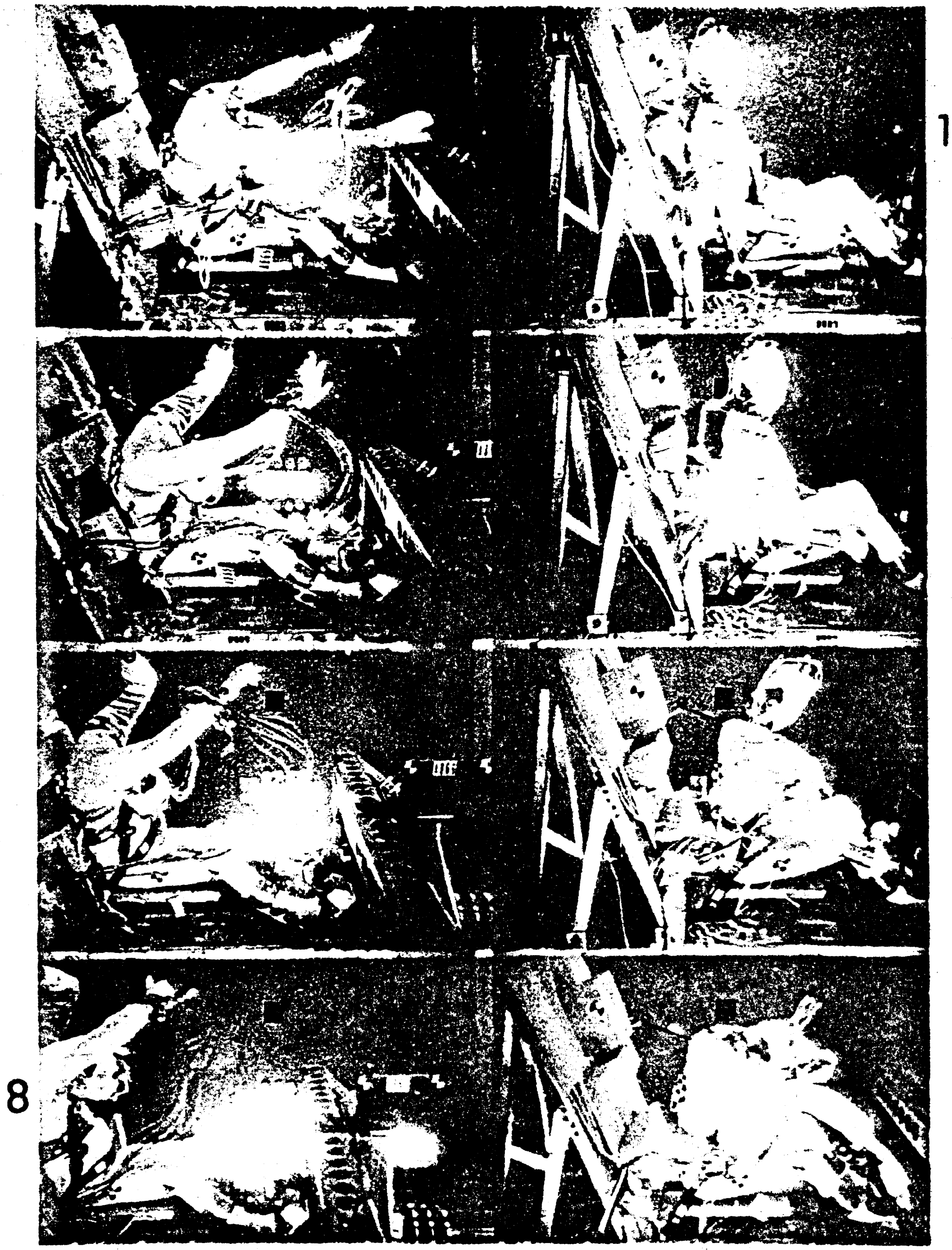
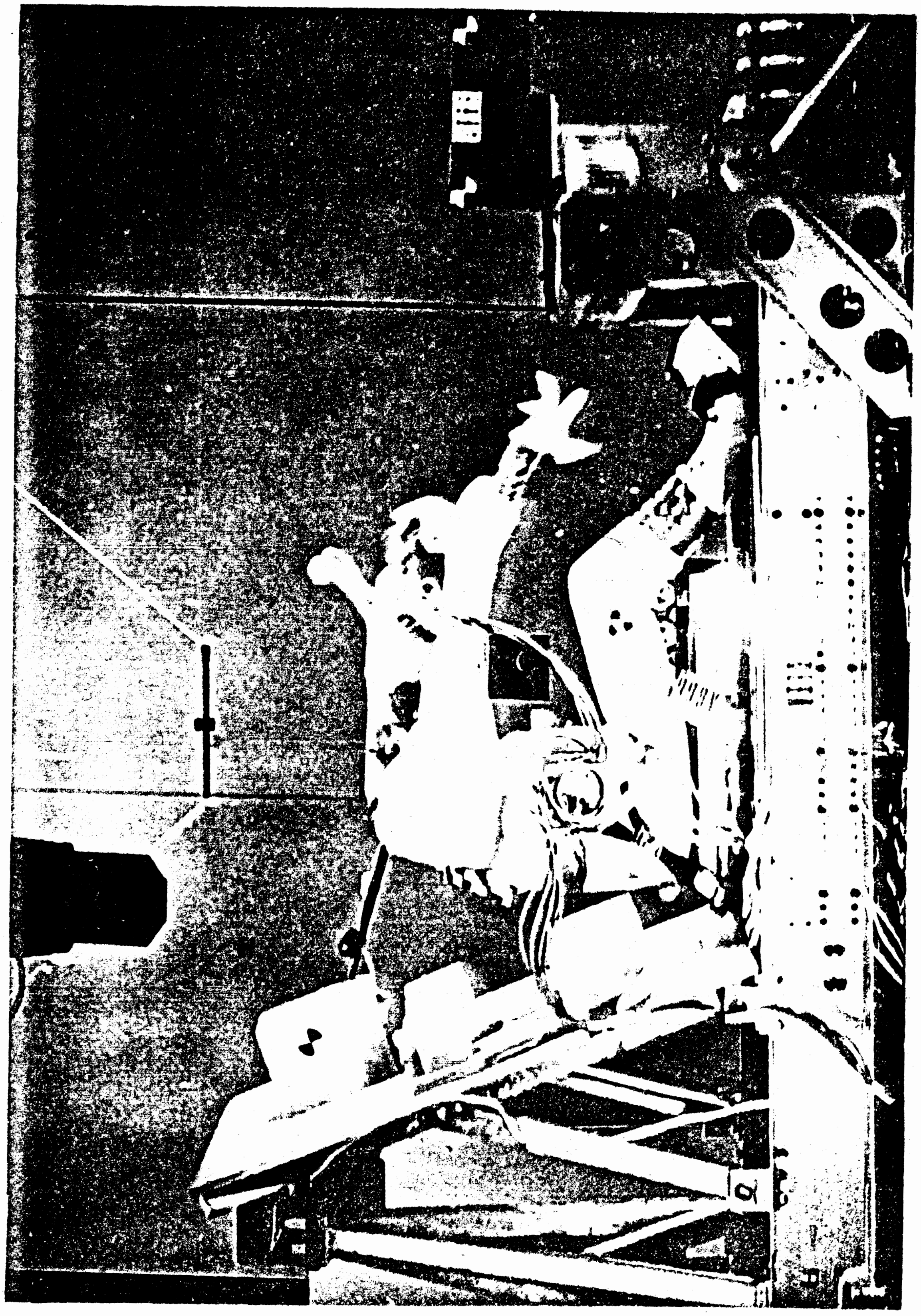
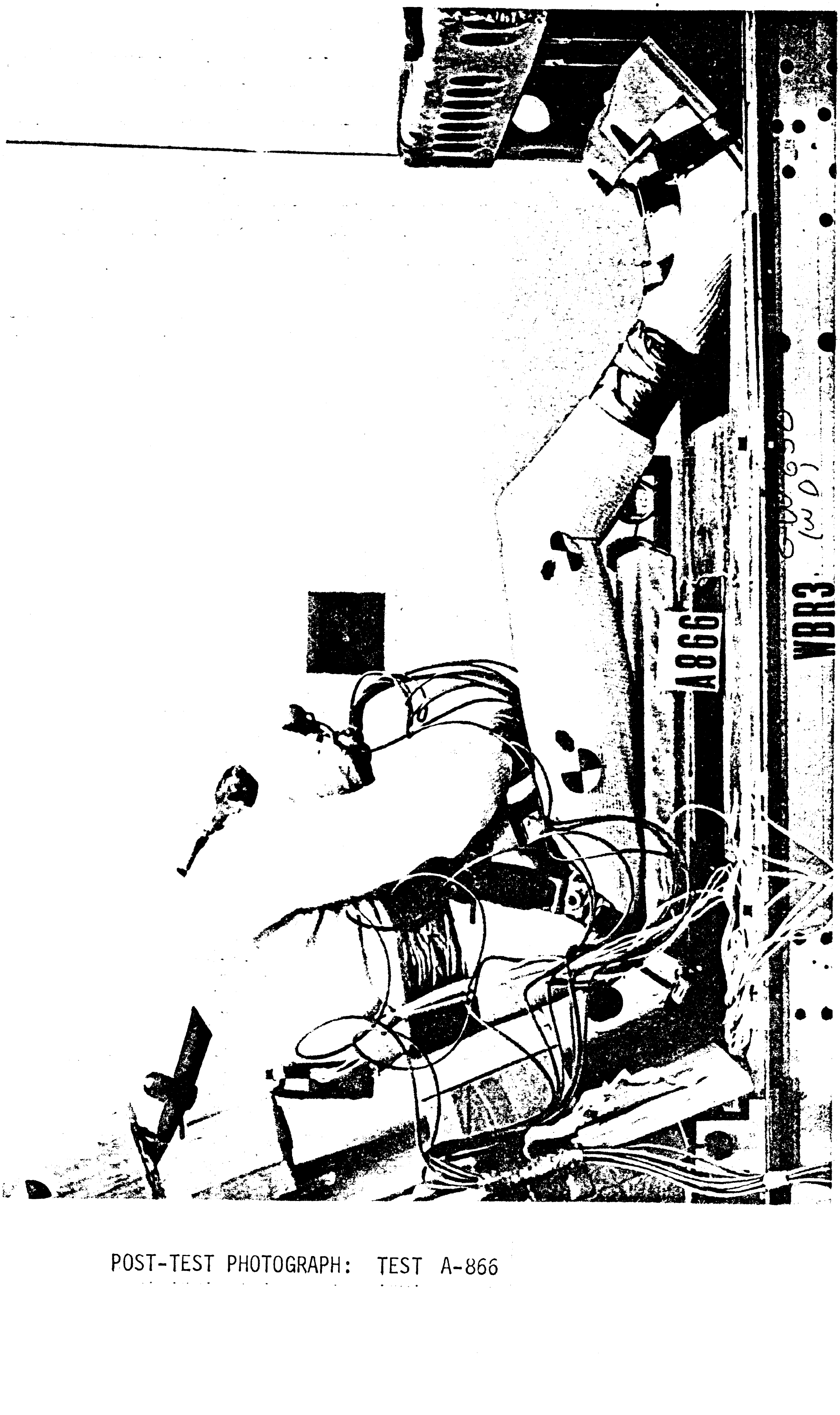


A866

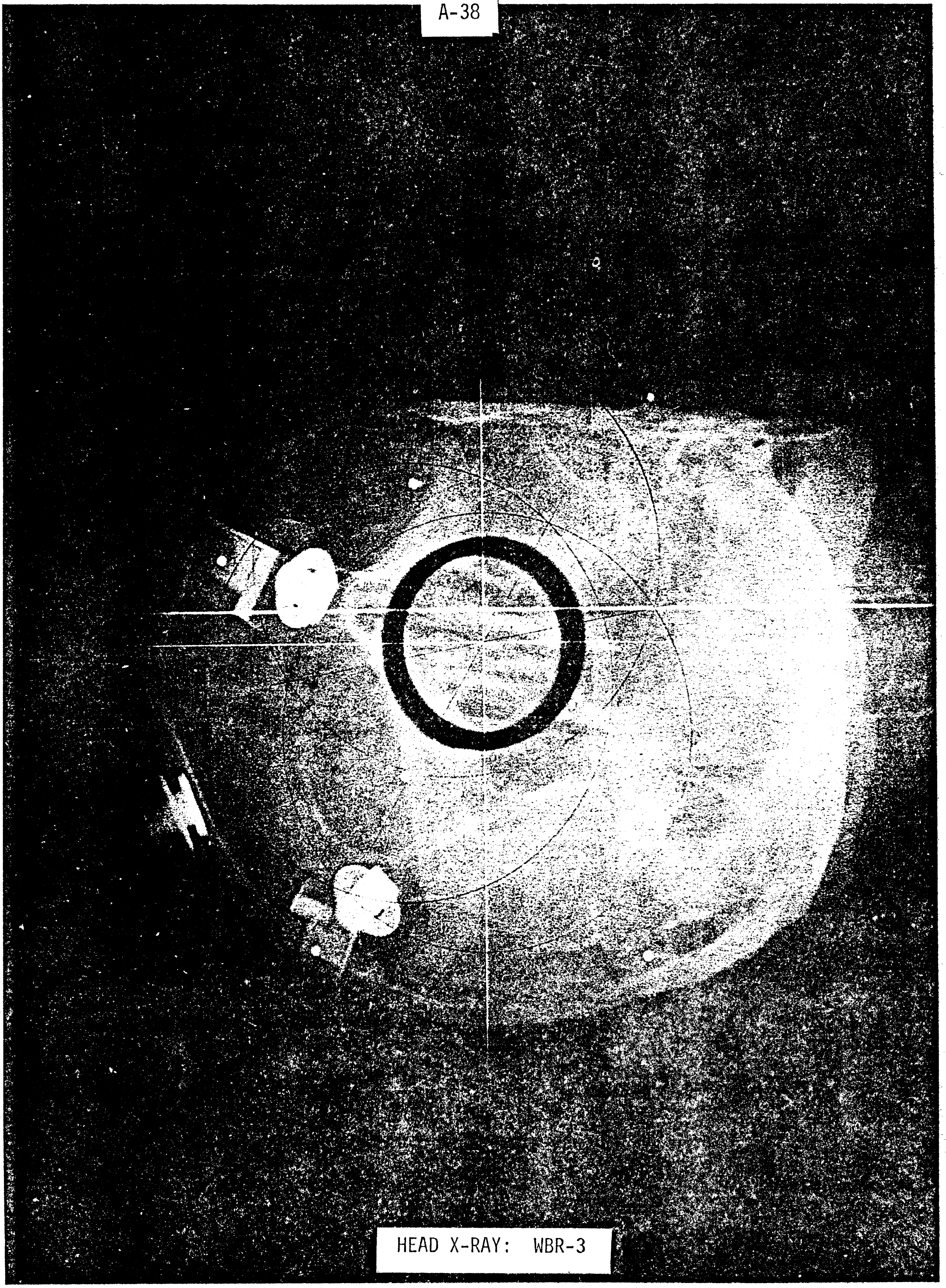
GRAPHCHECK PHOTOGRAPH: TEST A-866



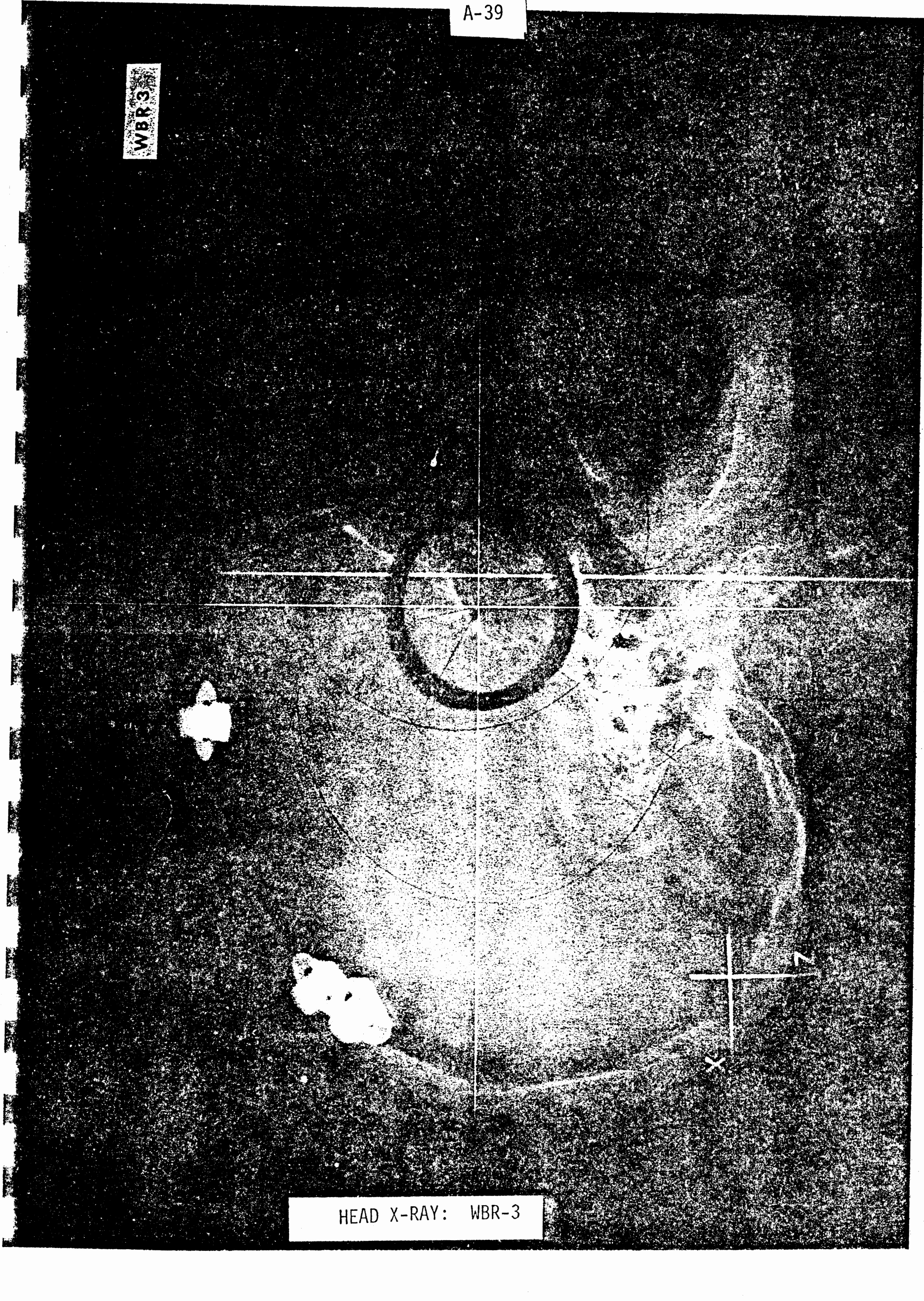
TEST PHOTOGRAPH: WBR-3 TEST A-866



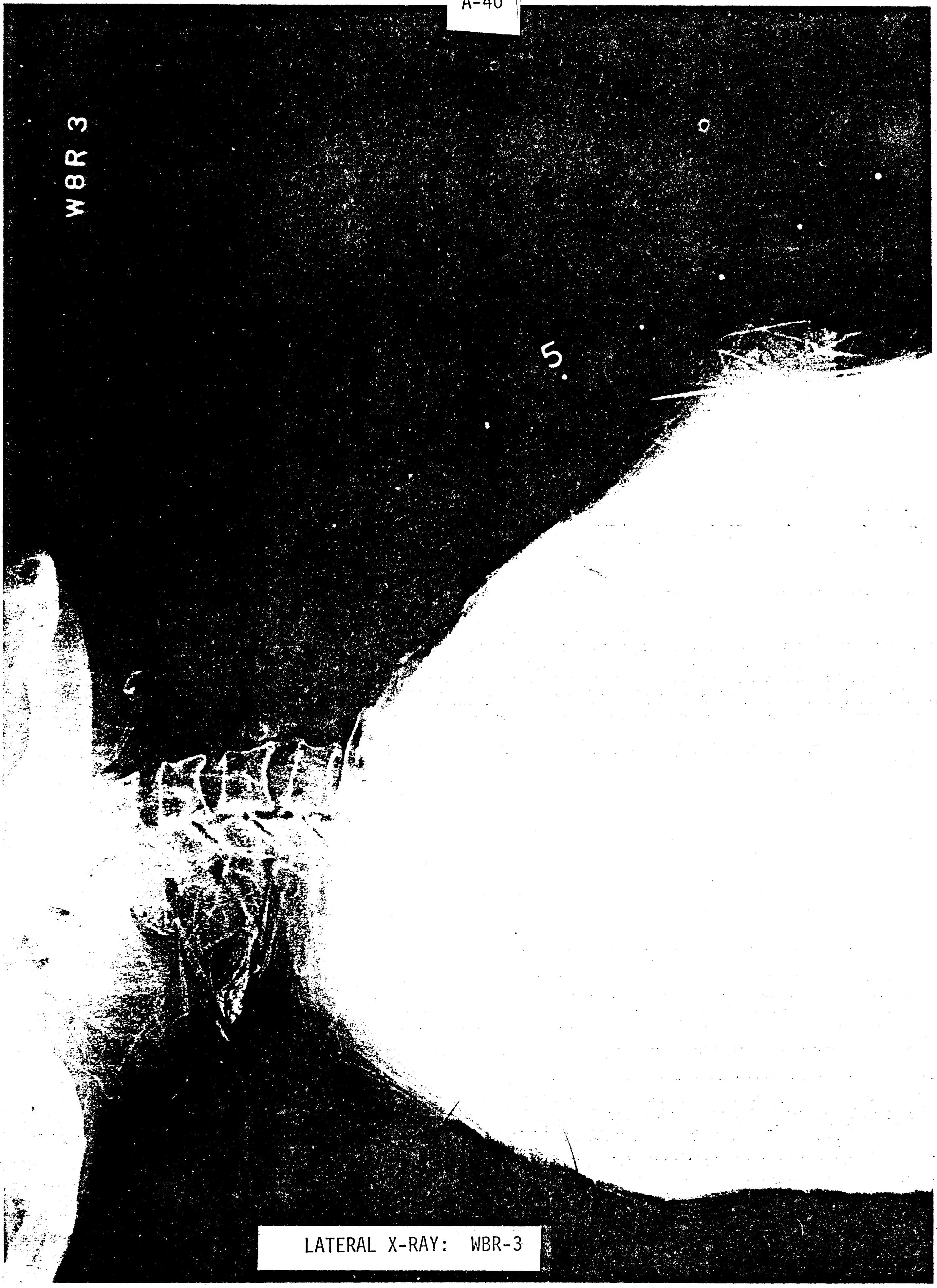
POST-TEST PHOTOGRAPH: TEST A-866



HEAD X-RAY: WBR-3



HEAD X-RAY: WBR-3

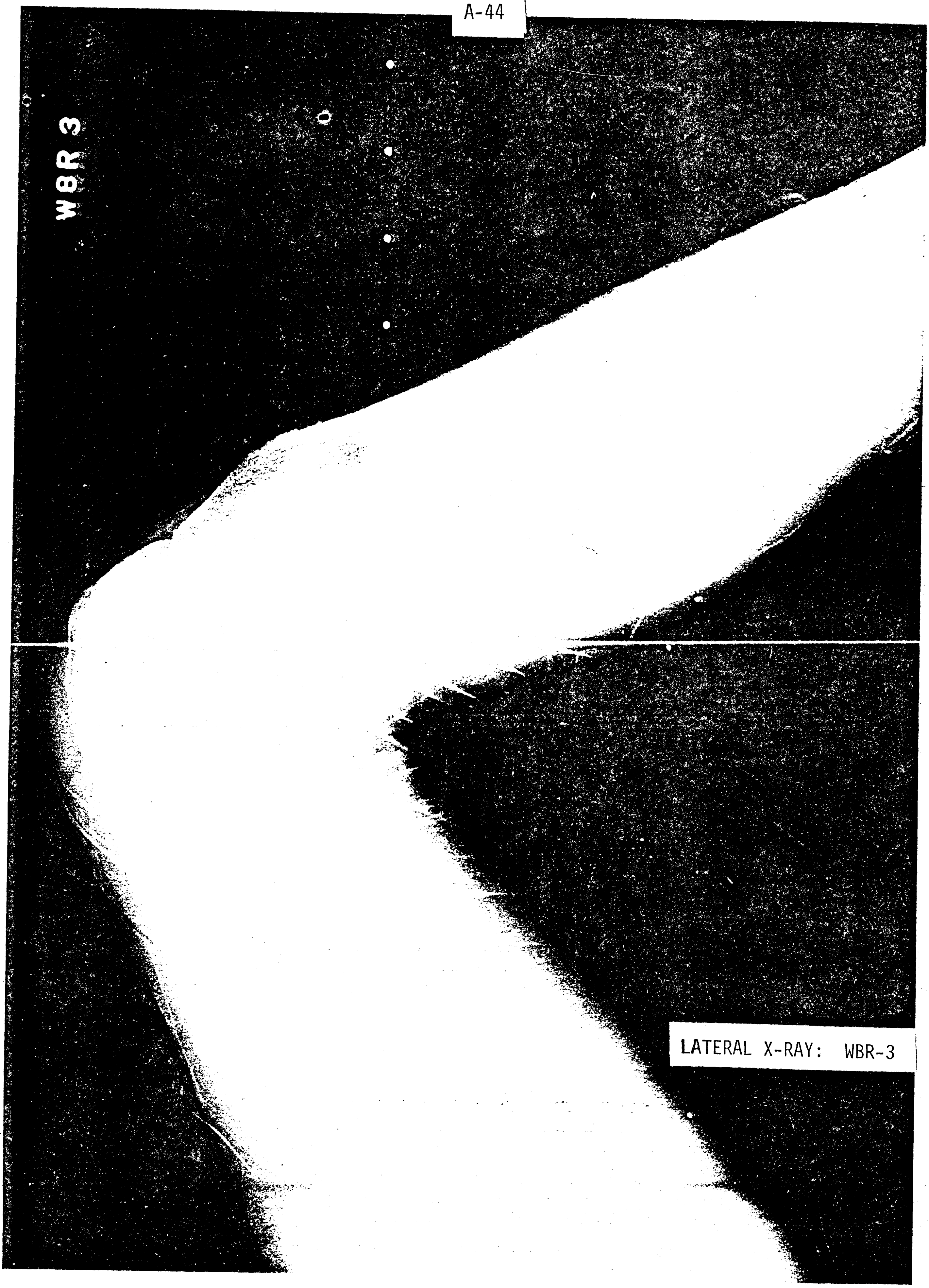


LATERAL X-RAY: WBR-3

LATERAL X-RAY: WBR-3

LATERAL X-RAY: WBR-3

LATERAL X-RAY: WBR-3



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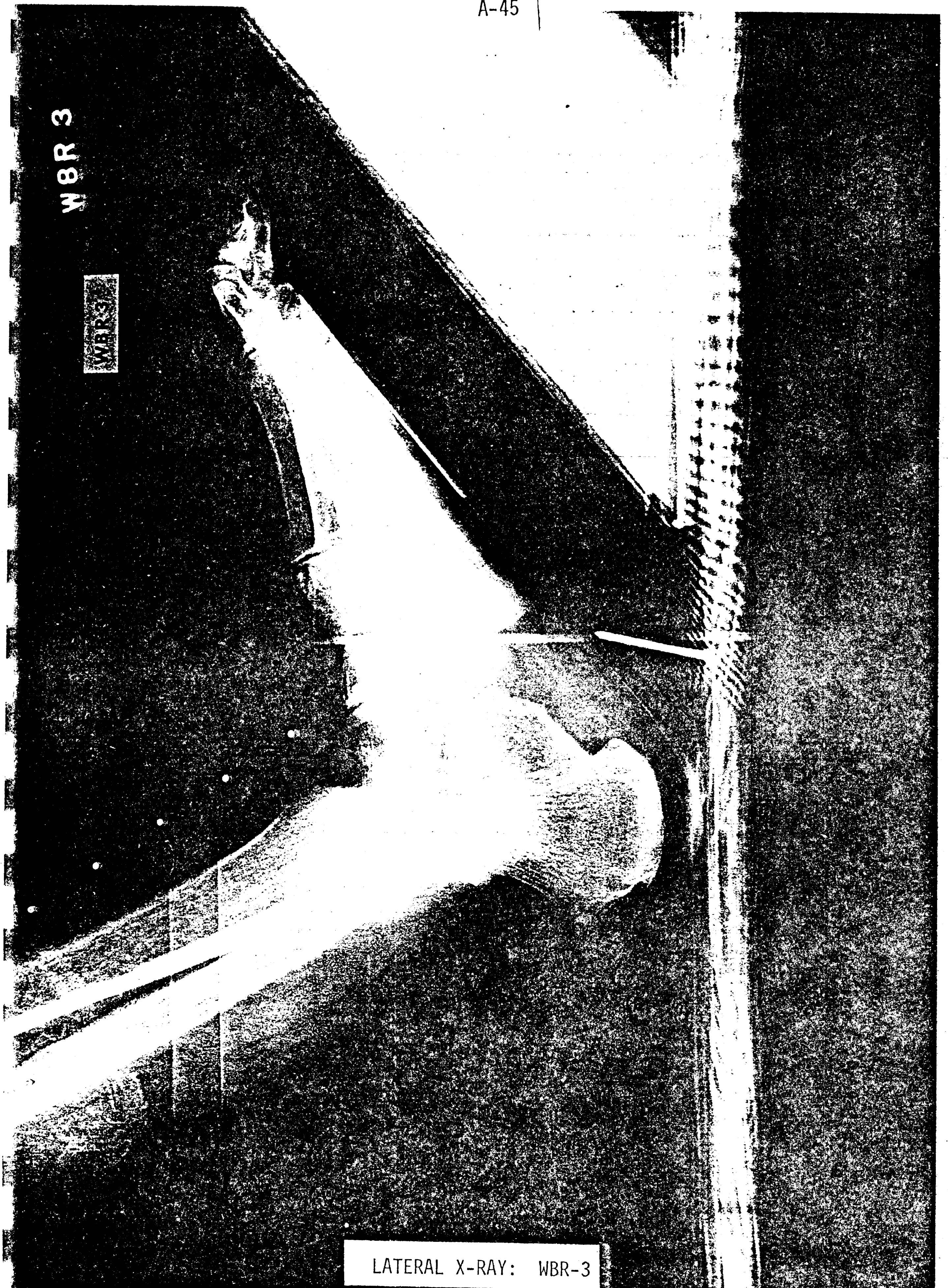
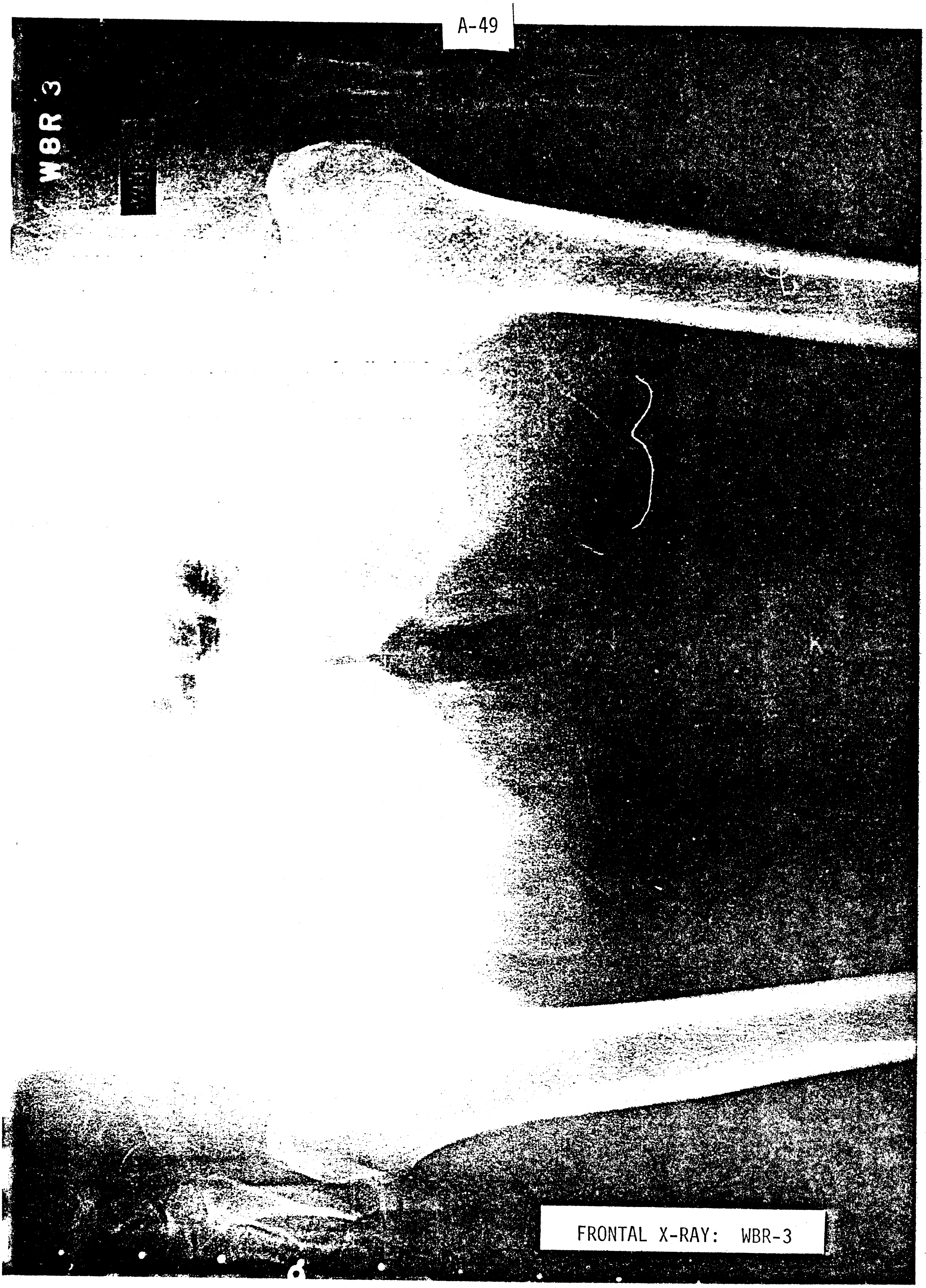


LATERAL X-RAY: WBR-3

FRONTAL X-RAY: WBR-3

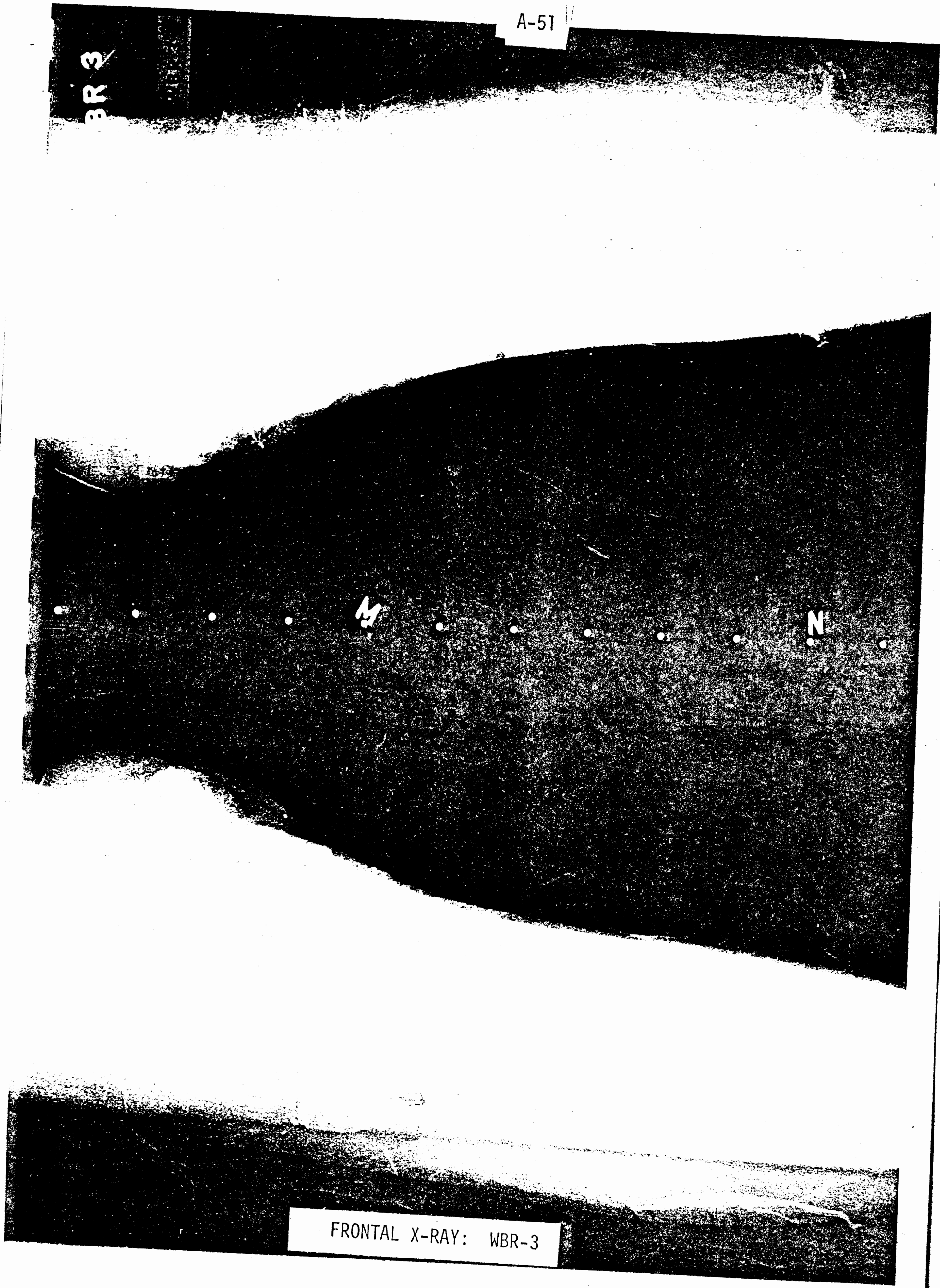
FRONTAL X-RAY: WBR-3

FRONTAL X-RAY: WBR-3

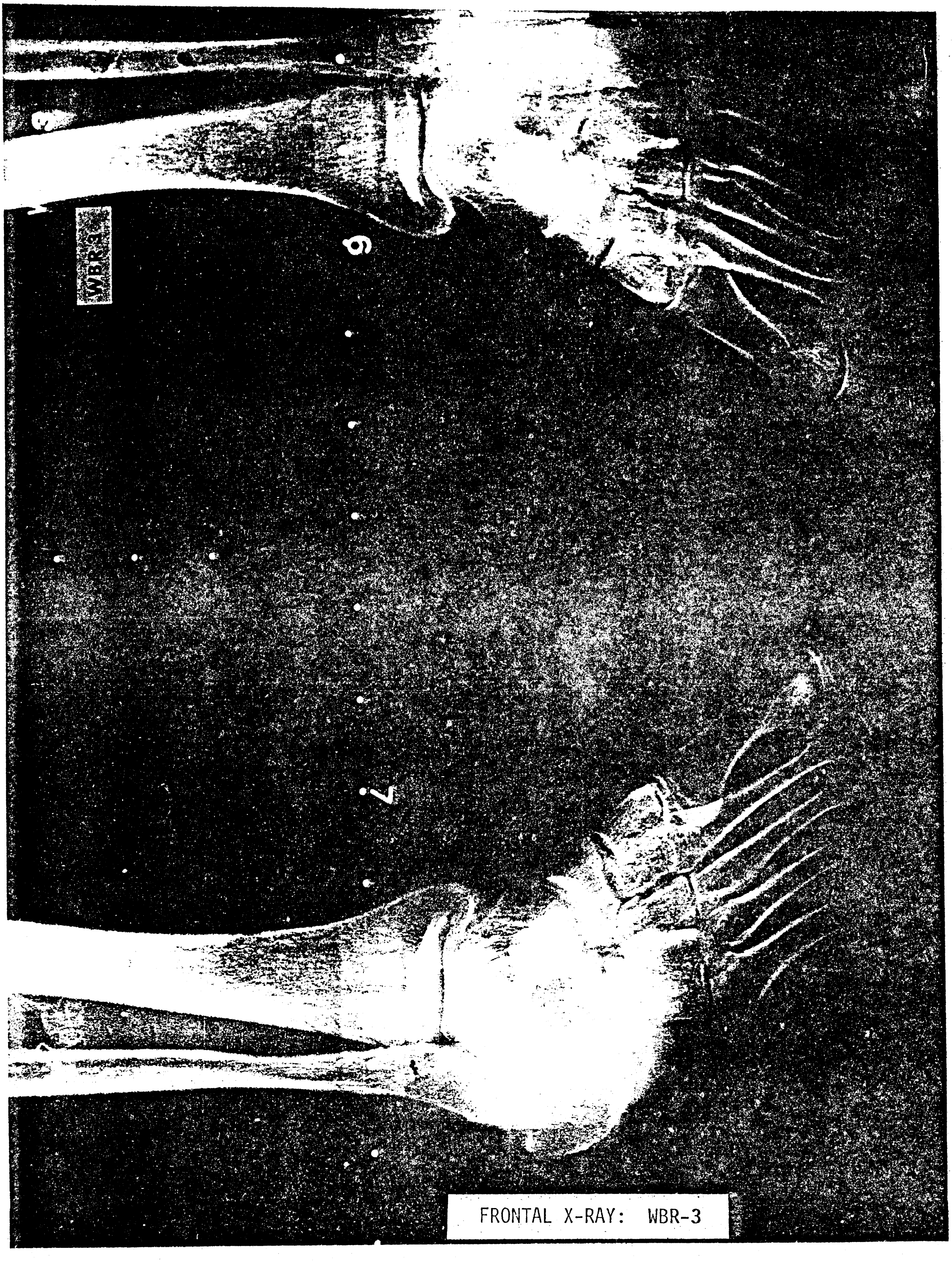


FRONTAL X-RAY: WBR-3

FRONTAL X-RAY: WBR-3



FRONTAL X-RAY: WBR-3



FRONTAL X-RAY: WBR-3

WHOLE BODY RESPONSE

TEST SUMMARY

TEST SERIES WBR-4

TESTS A-869 and A-870

WHOLE BODY RESPONSE

SLED TEST SUMMARY

WBR# 4 DATE 6-3-75

SLED TEST NOS. A- 869 AND A- 870

TEST SUBJECT DATA

CADAVER ID NO.: 20194 LUNGS PRESSURIZED: Yes

AGE: 82 years WEIGHT: 135 lbs.

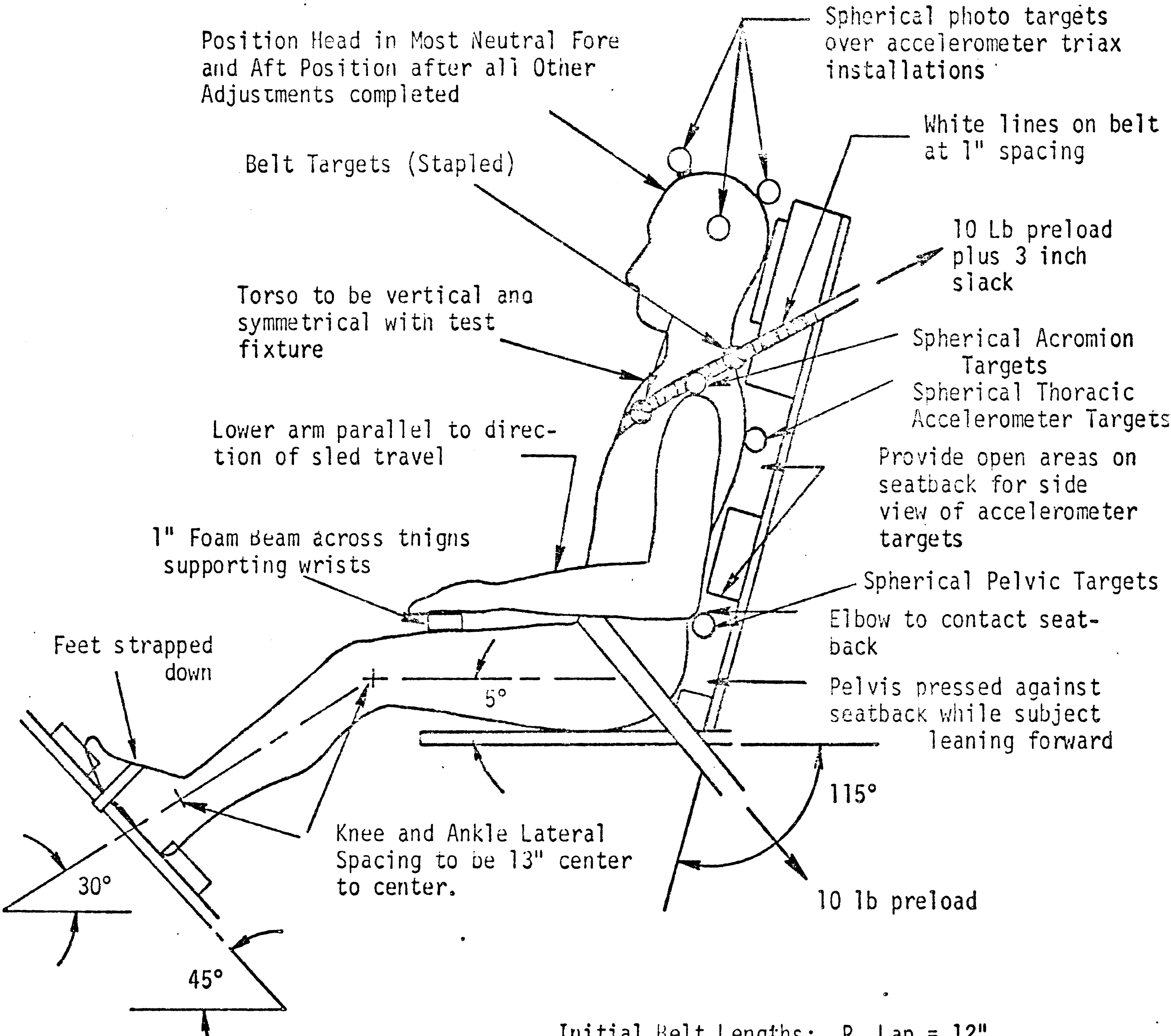
HEIGHT 165.5 cm. SEX: M

TEST PARAMETERS

	FIRST IMPACT	SECOND IMPACT
VELOCITY:	24.2 MPH	23.8 MPH
DECELERATION:	10.2 G's	9.6 G's
IMPACT DIRECTION:	FRONTAL	FRONTAL
RESTRAINT SYSTEM:	3 pt. belt	3 pt. belt

POST IMPACT EVALUATION

	FIRST IMPACT	SECOND IMPACT
a. Test Subject:		
Any Injury	None Apparent	
Submarining	None	None
b. Restraint System		
Damage:	None	None
c. Transducers:		
Any Units Damaged,	No	No
Any Units Loosened	No	No
d. Any Data Lost:	Thorax R to L	Thorax R to L



Initial Belt Lengths: R. Lap = 12"
(Center to Center of Ends) L. Lap = 32.5"
Shoulder = 42"

Femur Target Spacing:

Right Side = 6.0 in.

Left Side = 5 1/8 in.

POSITIONING AND TARGETING DIAGRAM WBR-4

WHOLE BODY RESPONSE WBR# 4

BELT LENGTH DATA

TEST A- 869

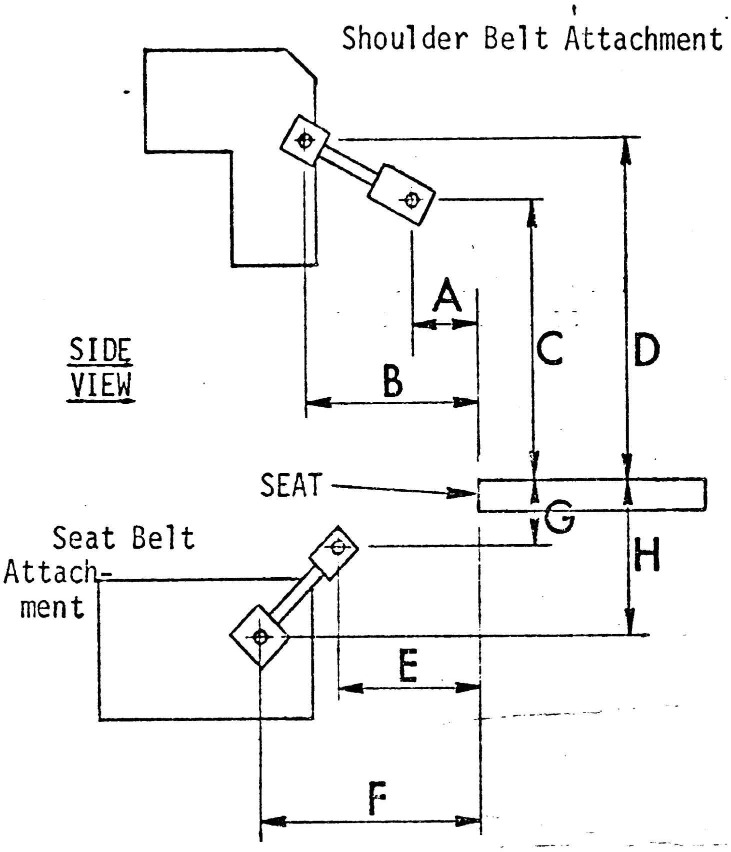
Belt Position	Pre-Impact Length (in)	Post-Impact Length (in)	Belt Stretch (in)	Post-Impact Length with Load Cells
Rt. Lap	12	12	0	11 1/4
Lt. Lap	32 1/2	33	1/2	32 5/8
Shoulder	42	42 1/4	1/4	40 5/8

Test A- 870

Belt Position	Pre-Impact Length (in)	Post-Impact Length (in)	Belt Stretch (in)	Post-Impact Length with Load Cells
Rt. Lap	12	12	0	11 1/4
Lt. Lap	32 1/2	33 1/8	5/8	32 1/4
Shoulder	42	42 3/8	3/8	41

BELT ANCHOR DATA

TEST WBR-4 A-869



SEAT BELT DIMENSIONS

RIGHT SIDE	LEFT SIDE
E = 3 3/8"	E = 5"
F = 7 1/8"	F = 7 1/8"
G = 5 7/8"	G = 9"
H = 11 1/4"	H = 11 1/4"

Belt Anchor Separations

L = 15"

M = 15 1/4"

SHOULDER BELT DIMENSIONS

A = 18 3/8"

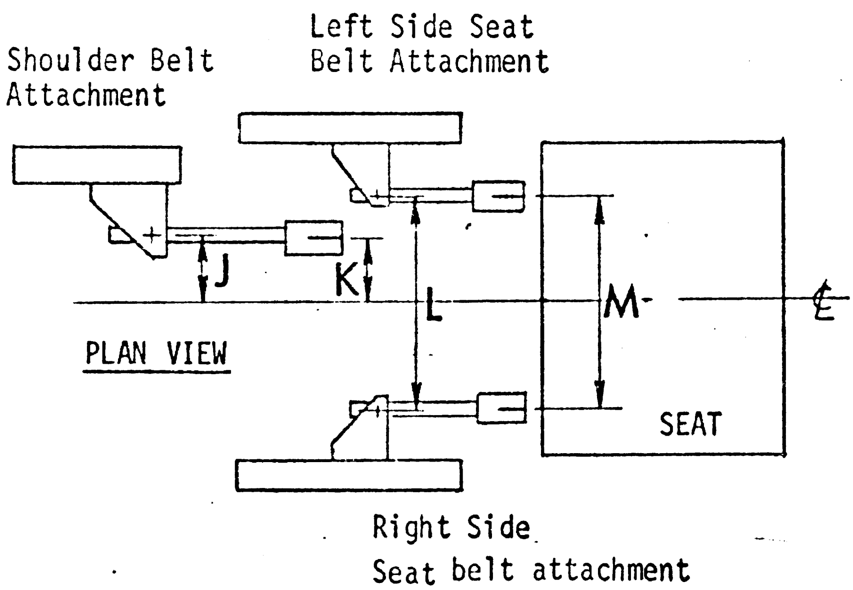
B = 23 7/8"

C = 36 3/8"

D = 39 1/2"

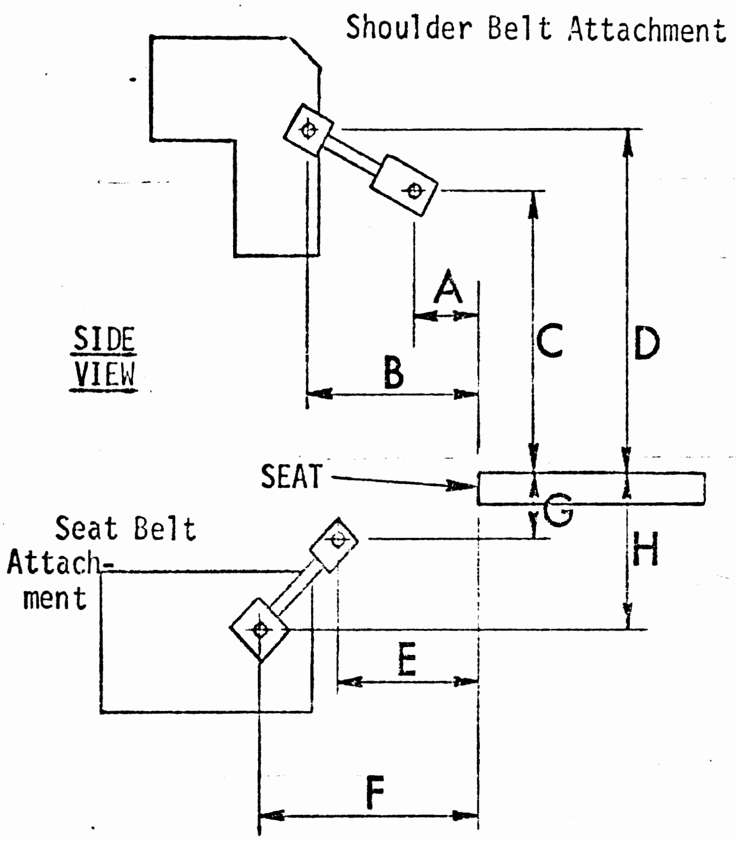
J = 6 1/2"

K = 5 3/4"



BELT ANCHOR DATA

TEST WBR-4 A-870



SEAT BELT DIMENSIONS

RIGHT SIDE		LEFT SIDE	
E =	3 1/2"	E =	5"
F =	6 5/8"	F =	6 5/8"
G =	7 3/8"	G =	9"
H =	11"	H =	11 1/2"

Belt Anchor Separations

L = 15"

M = 14"

SHOULDER BELT DIMENSIONS

A = 11"

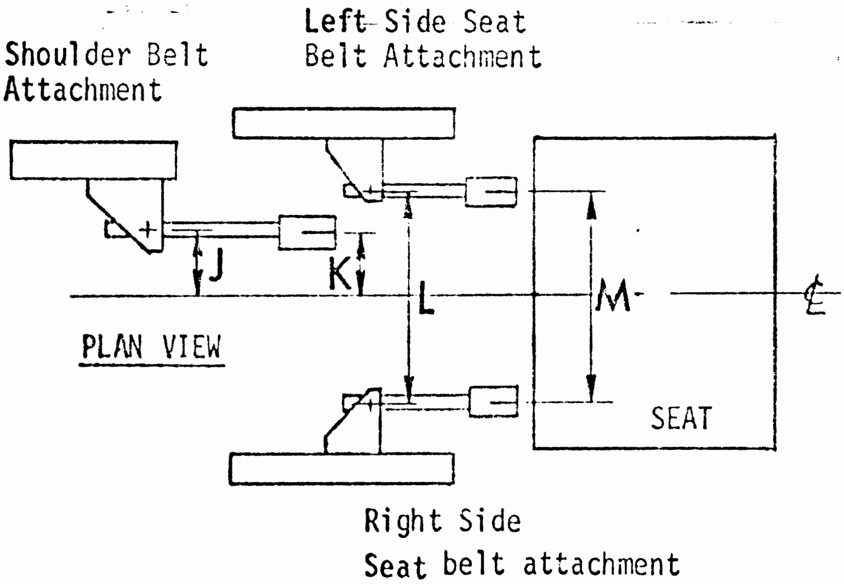
B = 5 1/4"

C = 28 1/8"

D = 32 3/8"

J = 8 "

K = 6 3/8"



INSTRUMENTATION DATA SHEET

TEST NO. WBR-4 SLED RUN NO. A-869; A-870 DATE 6-3-75 PREPARED BY

TAPE DATA: RECORDER Honeywell RECORD SPEED 30 IPS

	TAPE			TRANSDUCER			CALIBRATION						
CHAN.	INPUT	40% (3V) MODULATION VALUE	RUN GAIN	EXCIT. VOLT.	TYPE	S/N	CAL. RESISTOR	CAL. VOLTAGE	CAL. GAIN	CAL. VALUE	±	OUTPUT RUN SENSITIVITY	CHAN.
1	Sled Decel.		200		Stath	13587				22/G 44 G	+	20 G/V	1
2	Head Q- 1 A	-121.8 G	100	10	Endev	AB-56	199.3K	-1.17	100	47.5	-	40.60 G/V	2
3	Head Q- 1 B	-143.34 G	100	10	"	AB-59	200.0K	-1.17	100	55.9	-	47.78 G/V	3
4	Head Q- 1 C	-123.09 G	100	10	"	AB-60	199.6K	-1.17	100	47.6	-	41.03 G/V	4
5	Head Q- 2 C	-168.09 G	100	10	"	AB-61	199.4K	-1.16	100	65.0	-	56.03 G/V	5
6	Head Q- 2 A	-129.93 G	100	10	"	AB-79	199.4K	-1.18	100	51.1	-	43.31 G/V	6
7	Head Q- 2 B	-141.66 G	100	10	"	AB-85	199.5K	-1.15	100	54.3	-	47.22 G/V	7
8	Head Q 3 B	-116.67 G	100	10	"	AB-87	199.5K	-1.17	100	45.5	-	38.89 G/V	8
9	Head Q- 3 C	-128.43 G	100	10	"	AB-90	199.6K	-1.16	100	48.5	-	41.81 G/V	9
10	Head Q- 3 A	-130.02 G	100	10	"	AB-97	199.4K	-1.17	100	50.9	-	43.34 G/V	10
11													11
12	Velocity Pulse		10									12"/Pulse	12
13	Strobe		10									T_o Marker	13
14	Time Base											.01 sec/ pulse	14

INSTRUMENTATION DATA SHEET

TEST NO. WBR-4 SLED RUN NO. A-869, A-870 DATE 6-3-75 PREPARED BY

TAPE DATA: RECORDER CEC RECORD SPEED 30 IPS

	TAPE			TRANSDUCER			CALIBRATION						
CHAN.	INPUT	40% (3V) MODULATION VALUE	RUN GAIN	EXCIT. VOLT.	TYPE	S/N	CAL. RESISTOR	CAL. VOLTAGE	CAL. GAIN	CAL. VALUE	±	OUTPUT RUN SENSITIVITY	CHAN.
1	Sled Decel.		200		Stath	13587				22 G 44 G	+	20 G/V	1
2	Pelvis A-P	199.89G	100	10	Entrn	910X	102.5 K	.944	100	62.9G		66.63 G/V	2
3	Pelvis I-S	-200.19G	100	10	"	910Y	102.5 K	1.091	100	72.8G		66.73 G/V	3
4	Thorax P-A	283.67G	100	10	"	112Y	102.3 K	.875	100	59.4G		67.89 G/V	4
5	Thorax I-S	171.78G	100	10	"	112X	102.3 K	.861	100	49.3G		57.26 G/V	5
6													6
7	Rt. Lap	3012.3#	200	-	G.S.E	082	50 K	2.20	200	2209#	+	1004.1 #/V	7
8	Lt. Lap	3002.7#	200	-	"	083	50 K	2.24	200	2242#	+	1000.9 #/V	8
9	Up. Shldr.	3009.3#	VAR	-	"	084	50 K	2.27	-	2277#	+	1003.1 #/V	9
10	Low. Shldr.	2466.9#	VAR	-	"	085	50 K	2.73	-	2245#	+	822.3 #/V	10
11													11
12	Velocity		10										12
13	Strobe		10									T_o Marker	13
14	Time Base												14

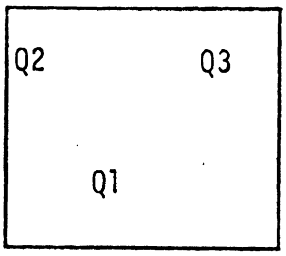
HEAD X-RAY DATA SHEET

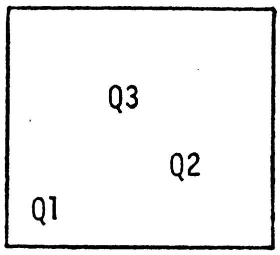
WHOLE BODY RESPONSE PROJECT

WBR NO. 4

TARGET		INSTALLATION FIXTURE DIMENSION	DISTANCE FROM X-RAY PLANE X-Z PLANE (Side view)	DISTANCE FROM X-RAY PLANE Y-Z PLANE (Frontal)
ACCELEROMETERS				
Location	Name			
Collet Furthest to Right-Rear of Head	Q_1	3.184	12.75	18.0
Next Collet clockwise from Q_1 (viewed from top)	Q_2	4.219	8.5	17.75
Next Collet clockwise from Q_2 (viewed from top)	Q_3	4.620	12.0	21.25
ANATOMICAL MARKER PELLETS				
Right Eye	□		7.5	24.5
Left Eye	□ with stem		6.25	23.0
Right Ear	○		10.5	24.0
Left Ear	○ with stem		6.5	1.5
X-RAY DATA				
VOLTAGE			90	90
CURRENT			100	100
TIME			.4	.4
SATISFACTORY? (Check if Yes)			✓	✓

Sketch of Relative Positions of Accelerometer Targets As Viewed from X-Ray Source.





WHOLE BODY RESPONSE: ANTHROPOMETRY

CADAVER ID: 20194

DATE: 5-30-75

ANTHROPOMETRIST: H. M. Reynolds

Anthropometric Measurements:

(A = Anthropometer; Sp. C. = Spreading Calipers; Sl. C. = sliding calipers; T = Tapes)

1.	Weight		61.5 kg
2.	Stature (A)		165.9 cm
3.	Trochanterion Hgt. (A)	Rt.	77.2
		Lt.	
4.	Anterior-Superior Iliac Spine Hgt. (A)	Rt.	72.9
		Lt.	71.6
5.	Iliocristale Hgt. (A)	Rt.	64.2
		Lt.	62.2
6.	Substernale Hgt. (A)		51.3
7.	Axilla Hgt. (A)		
8.	Suprasternale Hgt. (A)		30.7
9.	Nipple Hgt. (A)		
10.	Mastoid Hgt. (A)		16.0
11.	Nuchale Hgt. (A)		
12.	Tragion Hgt. (A)	Rt.	13.4
		Lt.	11.1
13.	Menton Hgt. (A)		
14.	Head Breadth (Sp. C.)		15.2
15.	Head Length (Sp. C.)		19.9

Cad. I.D. 20194

16.	Bitragion Diameter (Sp. C.)	14.6
17.	Bigonial Diameter (Sp. C.)	9.5
18.	Menton Diagonal (Sp. C.)	24.6
19.	Mastoid Diagonal (A)	16.2
20.	Head Circumference (T)	56.3
21.	Mid-Sagittal Arc Length (T)	33.9
22.	Coronal Arc Length (T)	34.0
23.	Mid-Neck Circumference (T)	34.2
24.	Chest Circumference at Axilla (T)	85.5
25.	Chest Circumference at Nipple (T)	
26.	Chest Circumference at Substernale (T)	87.9
27.	Hip Circumference, Iliocristale (T)	76.9
28.	Buttocks Circumference, Trochanterion (T)	
29.	Upper Arm Circumference, Axilla (T)	25.2
30.	Upper Arm Circumference, Mid Biceps (T)	23.2
31.	Upper Arm Circumference, Humeral Condyles (T)	23.1
32.	Maximum Forearm Circumference (T)	21.0
33.	Wrist Circumference (T)	15.4
34.	Upper Thigh Circumference (T)	43.1
35.	Mid-Thigh Circumference (T)	37.0
36.	Lower Thigh Circumference (T)	35.5
37.	Maximum Calf Circumference (T)	28.5
38.	Ankle Circumference (T)	21.9

Cad. I.D. 20194

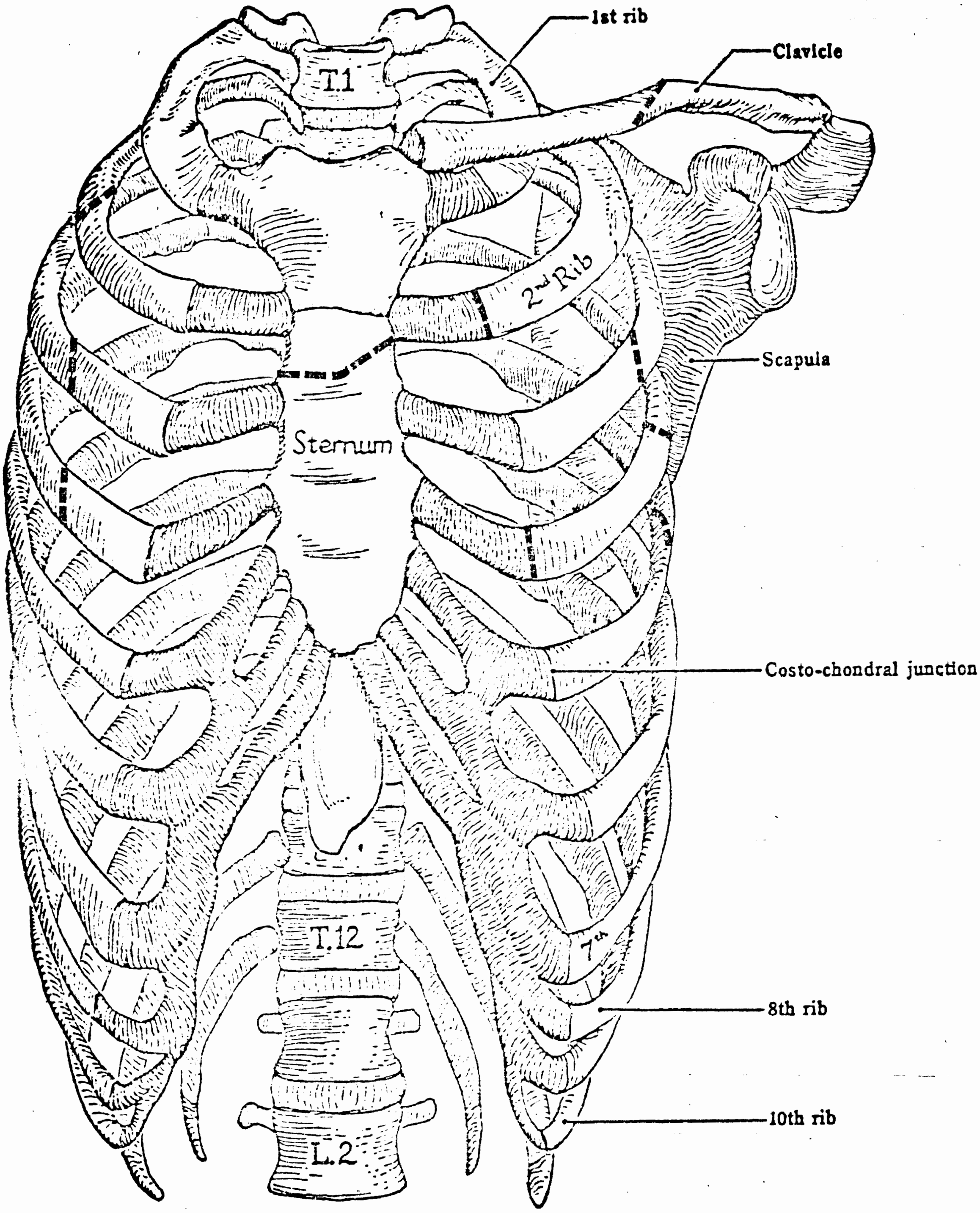
39.	Biacromial Diameter (A)		35.3
40.	Bideltoid Breadth (A)		36.5
41.	Chest Breadth at Axilla (A)		26.2
42.	Chest Breadth at Mid-Point between Suprasternale and Substernale		
43.	Chest Breadth at Substernale (A)		29.2
44.	Hip Breadth, Iliocristale (A)		29.4
45.	Bispinous Diameter (A)		25.1
46.	ASIS to Symphysion Distance (A)	Rt.	12.8
		Lt.	14.6
47.	Bitrochanteric Diameter (A)		
48.	Chest Depth at Suprasternale (A)		18.3
49.	Chest Depth at Axilla (A)		
50.	Chest Depth at Nipple (A)		
51.	Chest Depth at Substernale (A)		22.3
52.	Hip Depth, Iliocristale (A)		20.6
53.	ASIS Depth (A)	Rt.	15.4
		Lt.	16.6
54.	Buttocks Depth, Trochanterion (A)		17.1
55.	Trochanterion	Rt.	
		Lt.	
56.	Symphysion (Hgt.)		
57.	Acromion-Radiale Length		32.9

Cad. I.D. 20194

58. Ball of Humerus - Radiale Length (A)	30.4
59. Radiale-Stylion Length (A)	26.5
60. Olecronan-Stylion Length (A)	
61. Femur Length (A)	
62. Tibia Length (A)	40.0
63. Fibula Length (A)	38.0
64. Upper Arm Depth, Mid Biceps (Sl.C.)	
65. Humeral Biepicondylar Breadth (Sl.C.)	
66. Forearm Depth (Sl.C.)	
67. Wrist Depth (Sl.C.)	
68. Hand Length (Sl.C.)	19.1
69. Hand Breadth (Sl.C.)	
70. Hand Depth (Sl.C.)	
71. Thigh Breadth, Mid-Thigh (Sl.C,)	
72. Calf Depth (Sl.C.)	
73. Bimalleolus Breadth (Sl. C.)	
74. Foot Length (Sl.C.)	22.7
75. Foot Breadth (Sl.C.)	6.4

WHOLE BODY RESPONSE - WBR #4

AUTOPSY RESULTS



Bony Thorax, anterior aspect

RIB FRACTURE SITES ARE INDICATED BY DASHED LINES (-----)

OTHER INJURIES

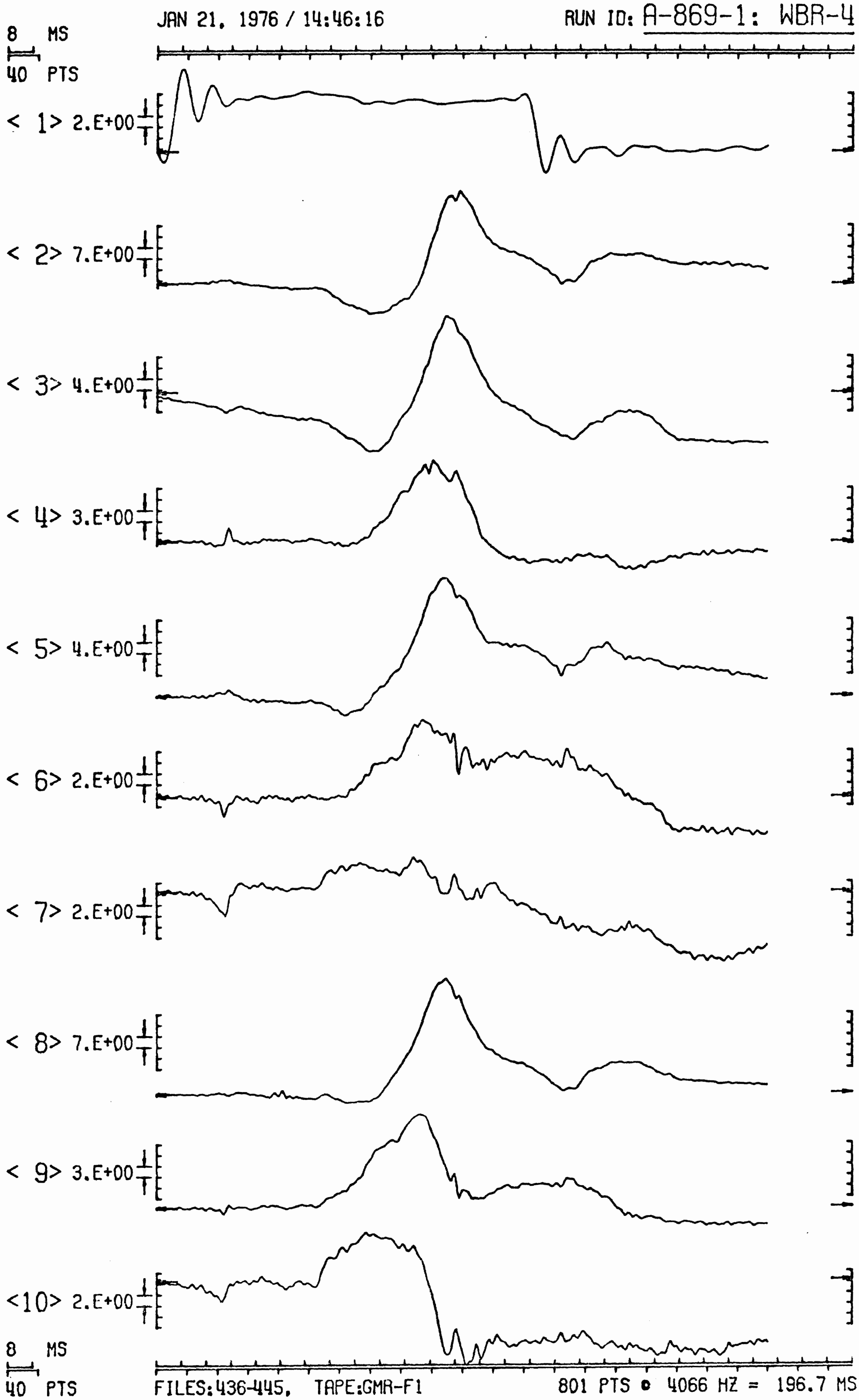
There was a belt burn on the left side of the neck.
The rib fractures are noted on the autopsy sheet.

TAPE: GMR-F1 DIGITAL SIGNAL FILTERING JAN 21, 1976 03:15:29 RUN ID: A-869-1: WBR-4

PROJECT: WHOLE BODY RESPONSE: CADAVER WBR-3 (9-ACC)

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
436 -	1:	SLED DECELERATION	G'S	801	4067.	LP(015-045)	(1)
437 -	2:	AX1 HEAD ACC (A)	G'S	801	4067.	LP(090-180)	(3)
438 -	3:	AY1 HEAD ACC (B)	G'S	801	4067.	LP(090-180)	(3)
439 -	4:	AZ1 HEAD ACC (C)	G'S	801	4067.	LP(090-180)	(3)
440 -	5:	AX2 HEAD ACC (C)	G'S	801	4067.	LP(090-180)	(3)
441 -	6:	AY2 HEAD ACC (A)	G'S	801	4067.	LP(090-180)	(3)
442 -	7:	AZ2 HEAD ACC (B)	G'S	801	4067.	LP(090-180)	(3)
443 -	8:	AX3 HEAD ACC (B)	G'S	801	4067.	LP(090-180)	(3)
444 -	9:	AY3 HEAD ACC (C)	G'S	801	4067.	LP(090-180)	(3)
445 -	10:	AZ3 HEAD ACC (A)	G'S	801	4067.	LP(090-180)	(3)
	11:						
	12:						

FILES: 436 - 445 ON TAPE: GMR-F1 RUN: A-869-1: WBR-4 FILTERED JAN 21, 1976 03:16:03



JAN 21, 1976 / 14:46:16
RUN ID: A-869-1: WBR-4
8 MS
40 PTS
< 1> 2.E+00
< 2> 7.E+00
< 3> 4.E+00
< 4> 3.E+00
< 5> 4.E+00
< 6> 2.E+00
< 7> 2.E+00
< 8> 7.E+00
< 9> 3.E+00
<10> 2.E+00
8 MS
40 PTS
FILES:436-445, TAPE:GMR-F1
801 PTS @ 4066 HZ = 196.7 MS

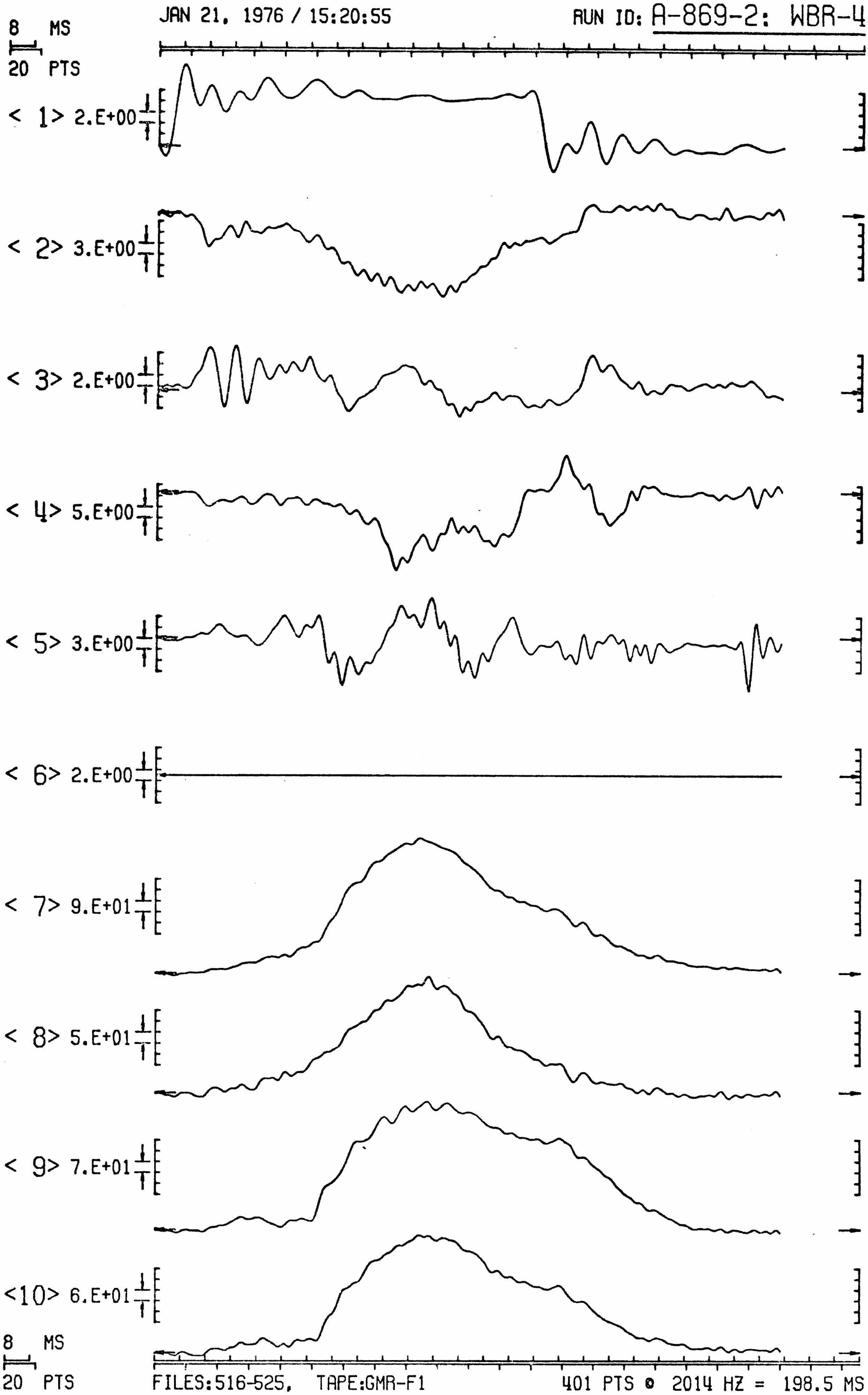
DIGITAL SIGNAL FILTERING

TAPE: GMR-F1 | JAN 21, 1976 03:29:02 | RUN ID: A-869-2: WBR-4

PROJECT: WHOLE BODY RESPONSE.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
516 -	1:	SLED DECELERATION	G'S	401	2015.	LP(030-030)	(4)
517 -	2:	PELVIS BIAX P-A ACC	G'S	401	2015.	LP(090-225)	(5)
518 -	3:	PELVIS BIAX I-S ACC	G'S	401	2015.	LP(090-225)	(5)
519 -	4:	THORAX TRIAX P-A ACC	G'S	401	2015.	LP(090-225)	(5)
520 -	5:	THORAX TRIAX I-S ACC	G'S	401	2015.	LP(090-225)	(5)
521 -	6:	THORAX TRIAX R-L ACC	G'S	401	2015.	LP(090-225)	(5)
522 -	7:	RIGHT LAP BELT LOAD	LBS	401	2015.	LP(090-225)	(5)
523 -	8:	LEFT LAP BELT LOAD	LBS	401	2015.	LP(090-225)	(5)
524 -	9:	UPPER SHOULDER BELT LOAD	LBS	401	2015.	LP(090-225)	(5)
525 -	10:	LOWER SHOULDER BELT LOAD	LBS	401	2015.	LP(090-225)	(5)
	11:						
	12:						

FILES: 516 - 525 ON TAPE: GMR-F1 RUN: A-869-2: WBR-4 FILTERED JAN 21, 1976 03:29:34


JAN 21, 1976 / 15:20:55
RUN ID: A-869-2: WBR-4
8 MS
20 PTS
< 1> 2.E+00
< 2> 3.E+00
< 3> 2.E+00
< 4> 5.E+00
< 5> 3.E+00
< 6> 2.E+00
< 7> 9.E+01
< 8> 5.E+01
< 9> 7.E+01
<10> 6.E+01
8 MS
20 PTS
FILES:516-525, TAPE:GMR-F1
401 PTS @ 2014 HZ = 198.5 MS

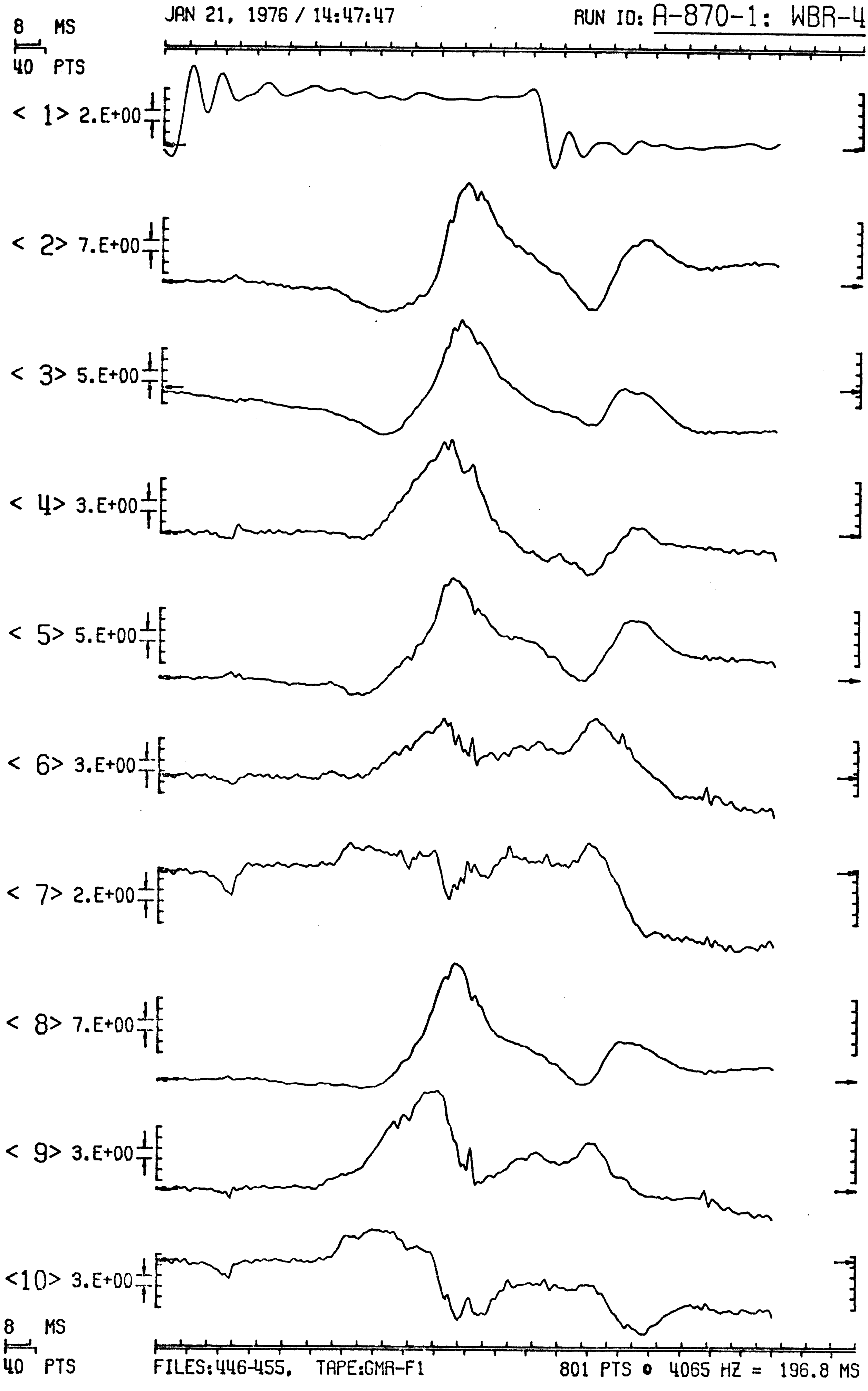
DIGITAL SIGNAL FILTERING

TAPE: GMR-F1 | JAN 21, 1976 03:17:00 | RUN ID: A-870-1: WBR-4

PROJECT: WHOLE BODY RESPONSE: CADAVER WBR-3 (9-ACC)

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
446 -	1:	SLED DECELERATION	G'S	801	4066.	LP(015-045)	(1)
447 -	2:	AX1 HEAD ACC (A)	G'S	801	4066.	LP(090-180)	(3)
448 -	3:	AY1 HEAD ACC (B)	G'S	801	4066.	LP(090-180)	(3)
449 -	4:	AZ1 HEAD ACC (C)	G'S	801	4066.	LP(090-180)	(3)
450 -	5:	AX2 HEAD ACC (C)	G'S	801	4066.	LP(090-180)	(3)
451 -	6:	AY2 HEAD ACC (A)	G'S	801	4066.	LP(090-180)	(3)
452 -	7:	AZ2 HEAD ACC (B)	G'S	801	4066.	LP(090-180)	(3)
453 -	8:	AX3 HEAD ACC (B)	G'S	801	4066.	LP(090-180)	(3)
454 -	9:	AY3 HEAD ACC (C)	G'S	801	4066.	LP(090-180)	(3)
455 -	10:	AZ3 HEAD ACC (A)	G'S	801	4066.	LP(090-180)	(3)
	11:						
	12:						

FILES: 446 - 455 ON TAPE: GMR-F1 RUN: A-870-1: WBR-4 FILTERED JAN 21, 1976 03:17:33


JAN 21, 1976 / 14:47:47
RUN ID: A-870-1: WBR-4
8 MS
40 PTS
< 1> 2.E+00
< 2> 7.E+00
< 3> 5.E+00
< 4> 3.E+00
< 5> 5.E+00
< 6> 3.E+00
< 7> 2.E+00
< 8> 7.E+00
< 9> 3.E+00
<10> 3.E+00
8 MS
40 PTS
FILES:446-455, TAPE:GMR-F1
801 PTS @ 4065 HZ = 196.8 MS

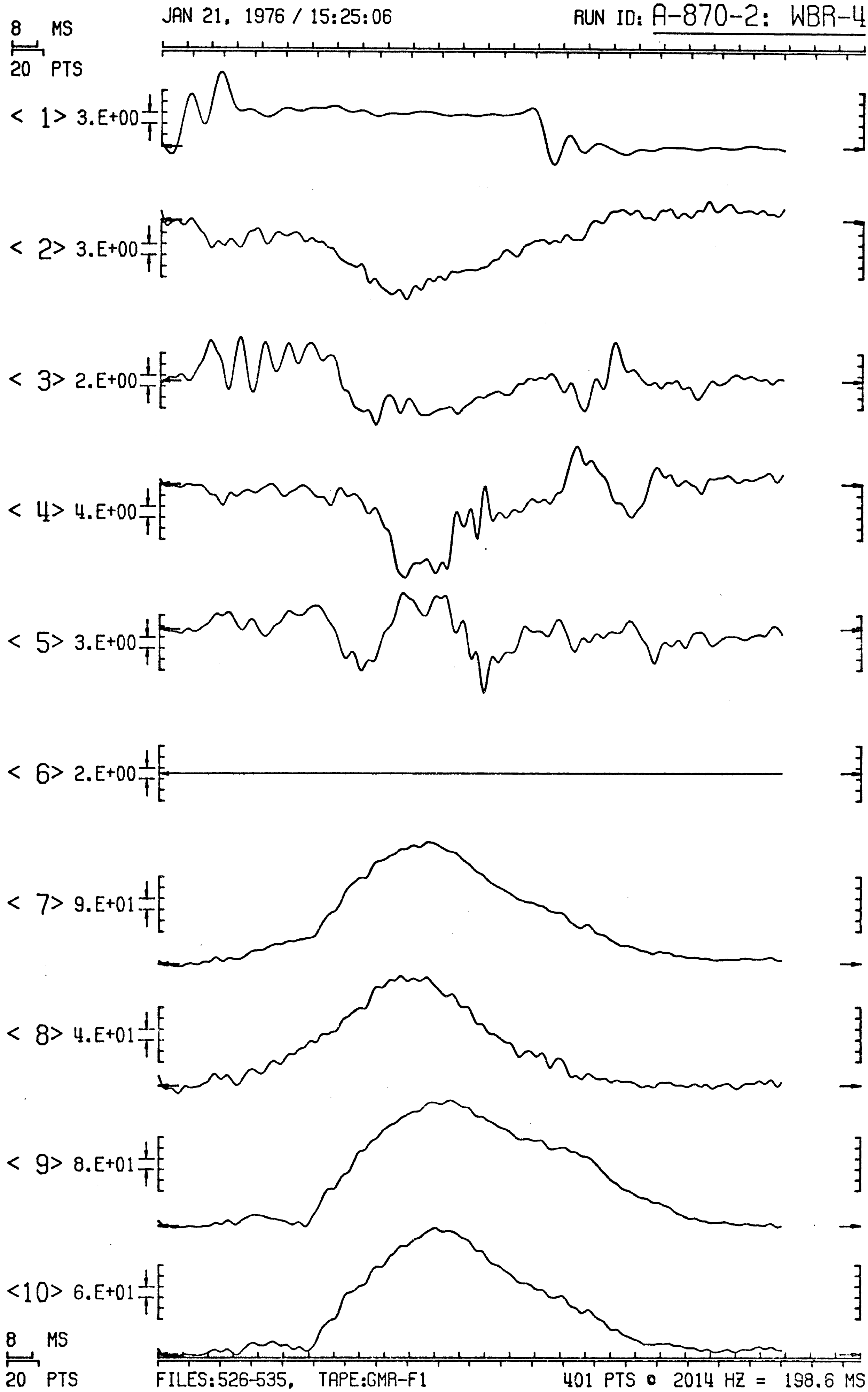
DIGITAL SIGNAL FILTERING

TAPE: GMR-F1 JAN 21, 1976 03:30:38 RUN ID: A-870-2: WBR-4

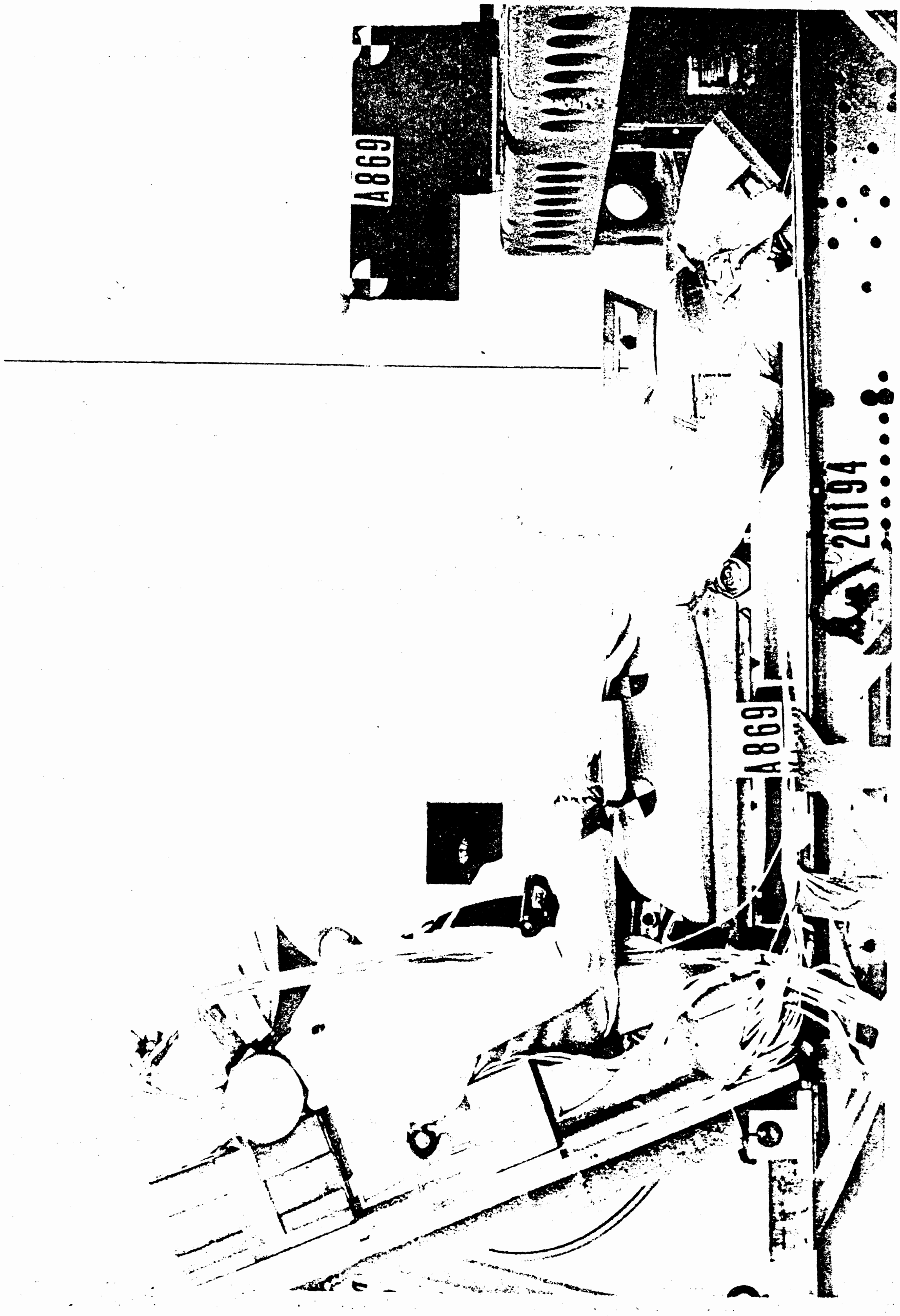
PROJECT: WHOLE BODY RESPONSE.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
526 -	1:	SLED DECELERATION	G'S	401	2015.	LP(030-090)	(4)
527 -	2:	PELVIS BIAX P-A ACC	G'S	401	2015.	LP(090-225)	(5)
528 -	3:	PELVIS BIAX I-S ACC	G'S	401	2015.	LP(090-225)	(5)
529 -	4:	THORAX TRIAX P-A ACC	G'S	401	2015.	LP(090-225)	(5)
530 -	5:	THORAX TRIAX I-S ACC	G'S	401	2015.	LP(090-225)	(5)
531 -	6:	THORAX TRIAX R-L ACC	G'S	401	2015.	LP(090-225)	(5)
532 -	7:	RIGHT LAP BELT LOAD	LBS	401	2015.	LP(090-225)	(5)
533 -	8:	LEFT LAP BELT LOAD	LBS	401	2015.	LP(090-225)	(5)
534 -	9:	UPPER SHOULDER BELT LOAD	LBS	401	2015.	LP(090-225)	(5)
535 -	10:	LOWER SHOULDER BELT LOAD	LBS	401	2015.	LP(090-225)	(5)
	11:						
	12:						

FILES: 526 - 535 ON TAPE: GMR-F1 RUN: A-870-2: WBR-4 FILTERED JAN 21, 1976 03:31:10

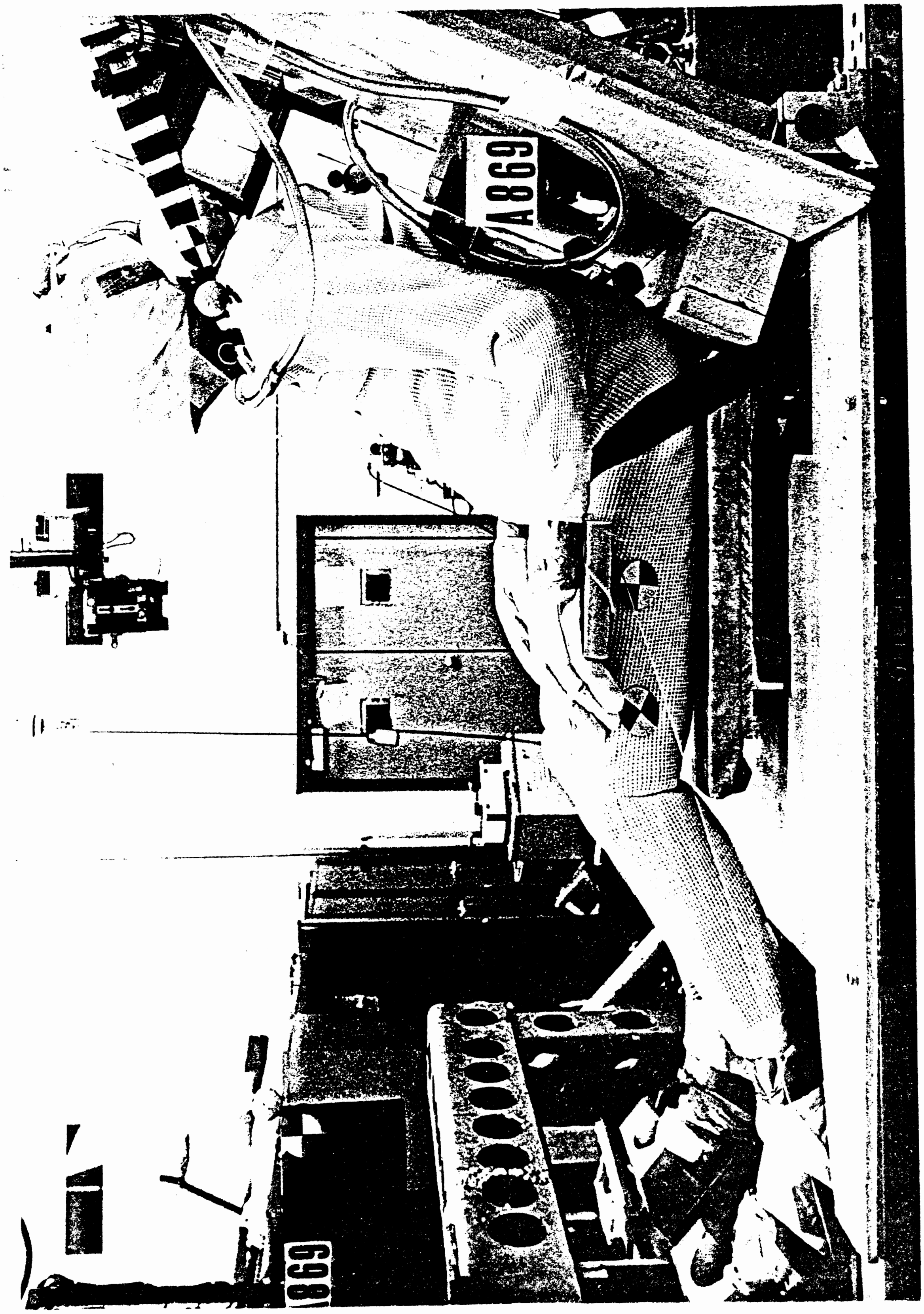


JAN 21, 1976 / 15:25:06
RUN ID: A-870-2: WBR-4
8 MS
20 PTS
< 1> 3.E+00
< 2> 3.E+00
< 3> 2.E+00
< 4> 4.E+00
< 5> 3.E+00
< 6> 2.E+00
< 7> 9.E+01
< 8> 4.E+01
< 9> 8.E+01
<10> 6.E+01
8 MS
20 PTS
FILES:526-535, TAPE:GMR-F1
401 PTS @ 2014 HZ = 198.6 MS

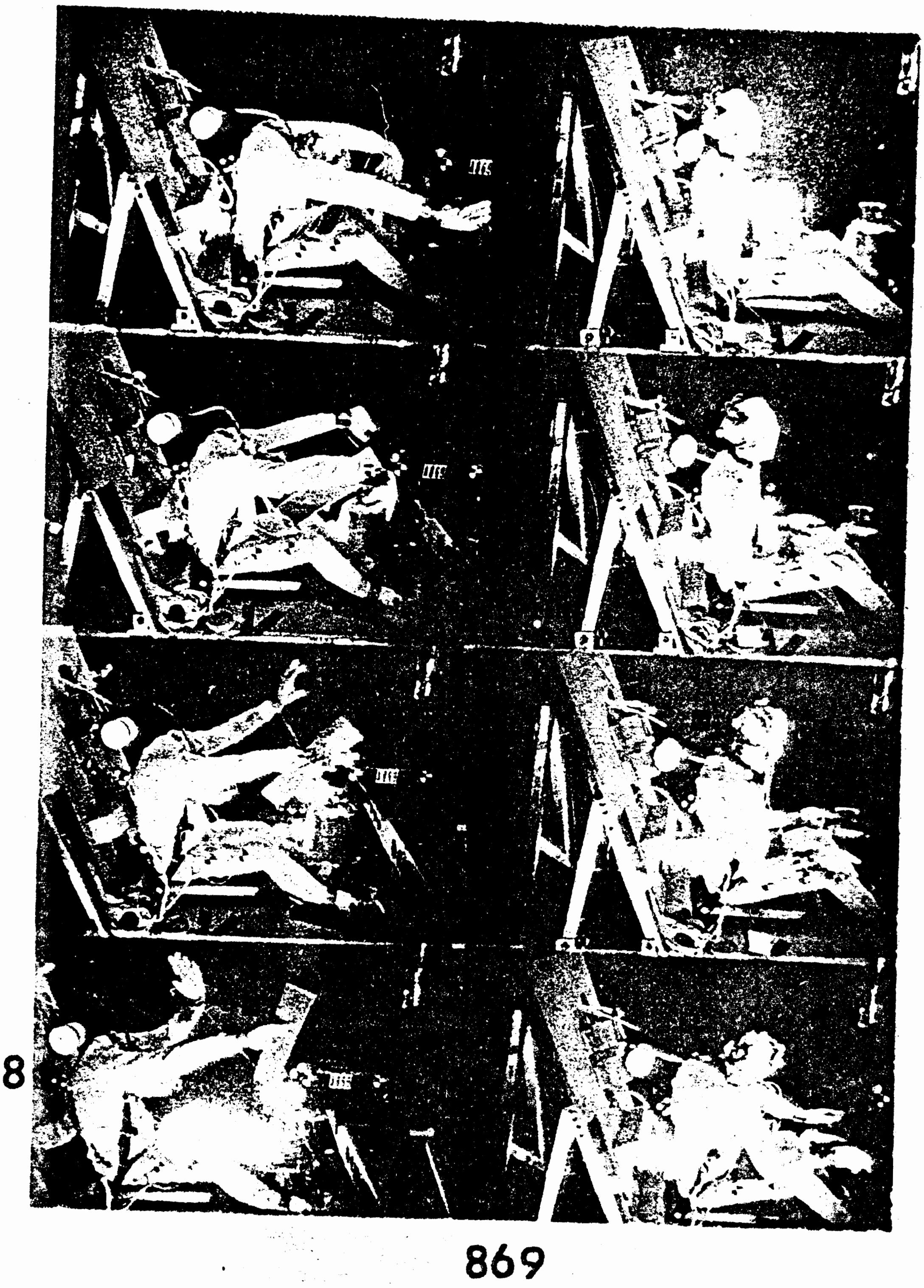


SETUP PHOTOGRAPH: TEST A-869

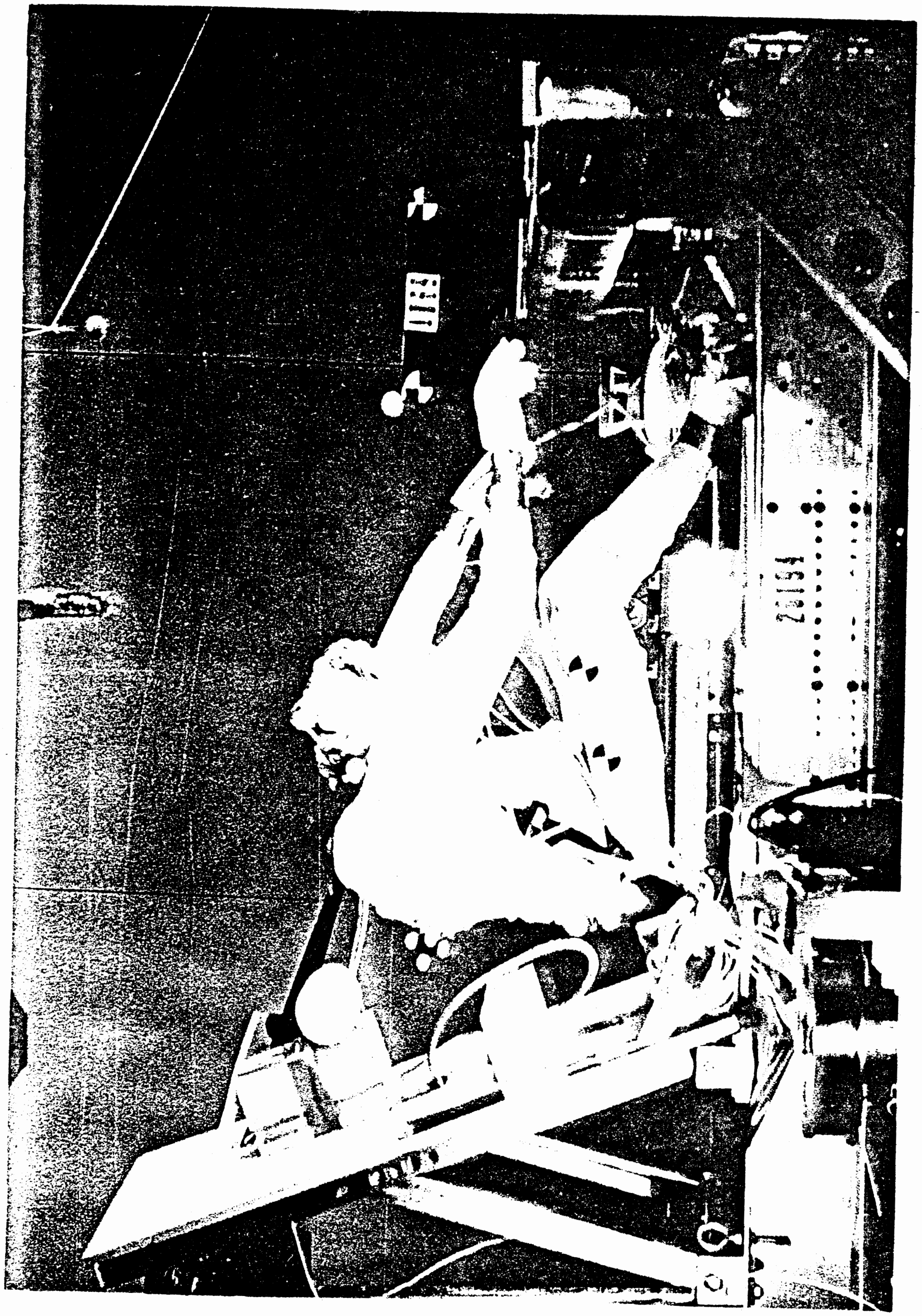
SETUP PHOTOGRAPH: TEST A-869



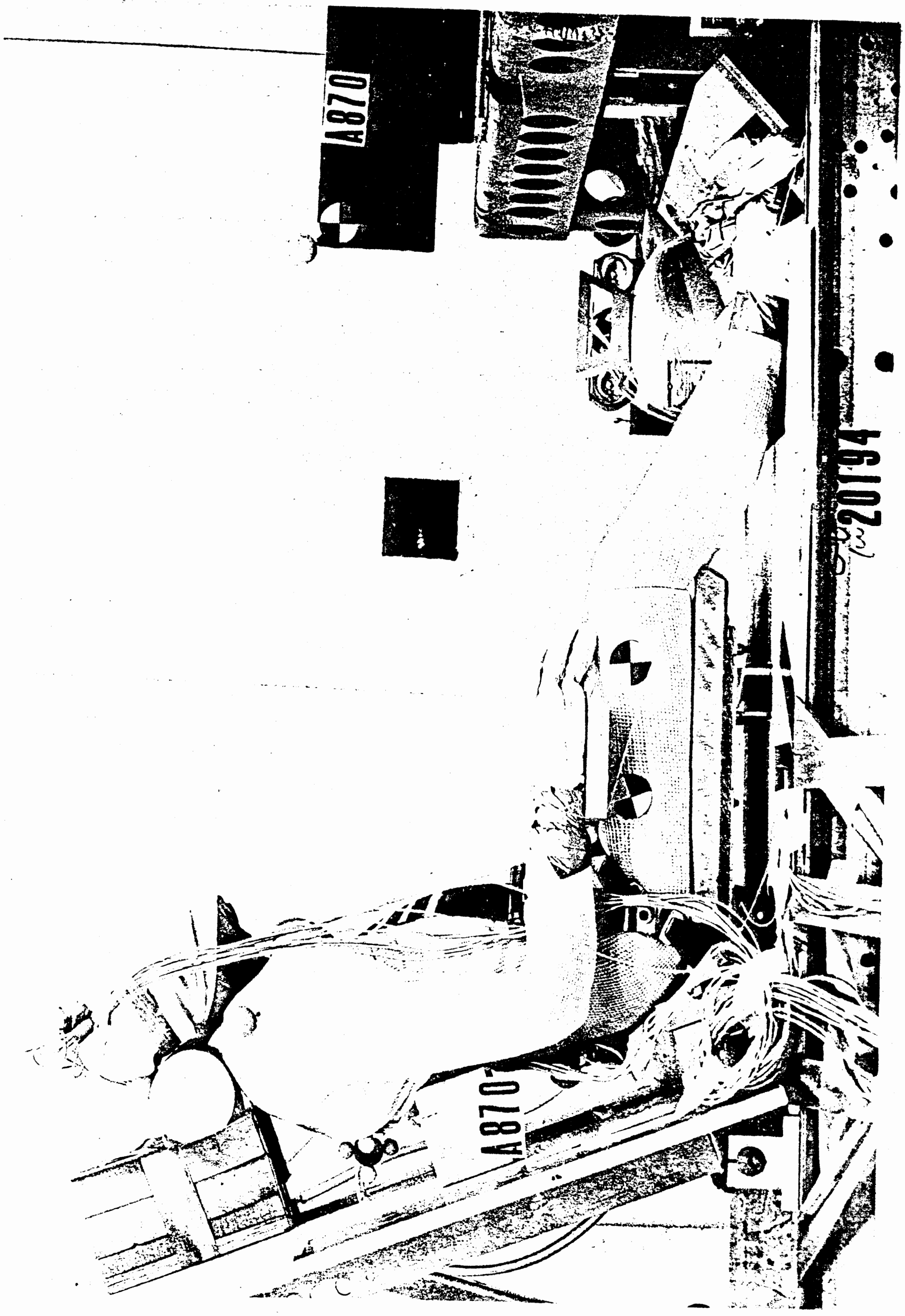
SETUP PHOTOGRAPH: TEST A-869



GRAPHCHECK PHOTOGRAPH: TEST A-869

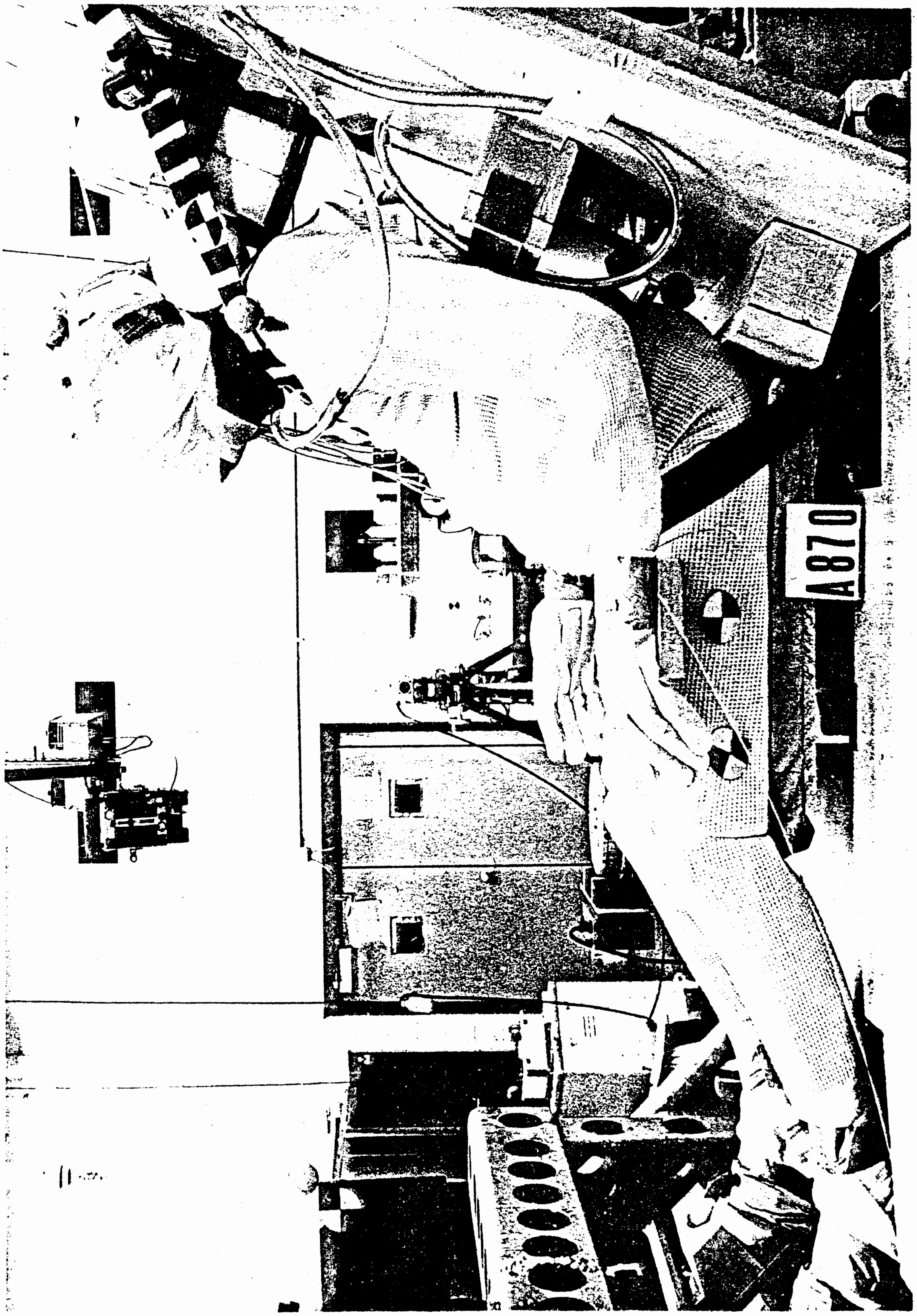


TEST PHOTOGRAPH: WBR-4 TEST A-869

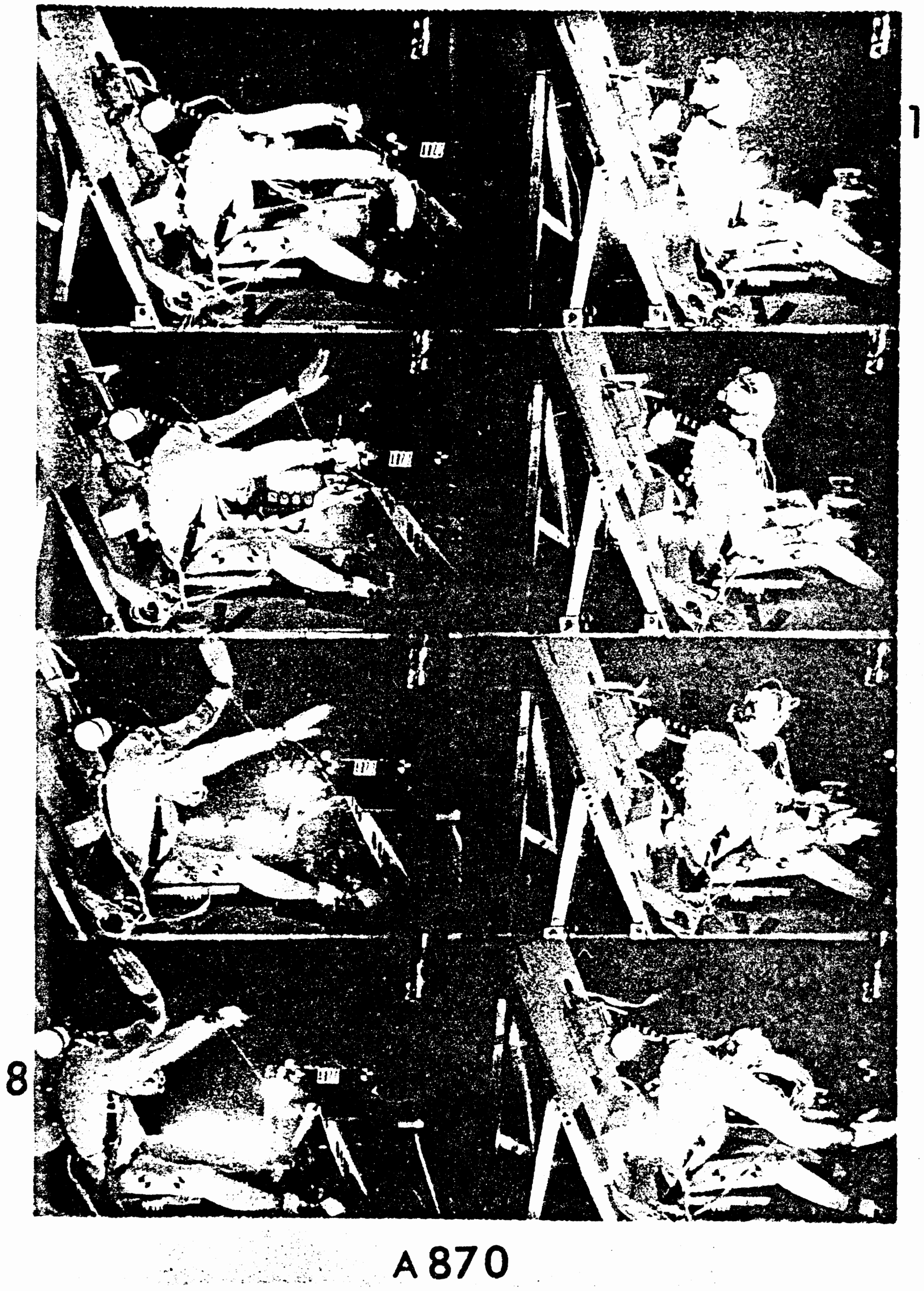


SETUP PHOTOGRAPH: TEST A-870

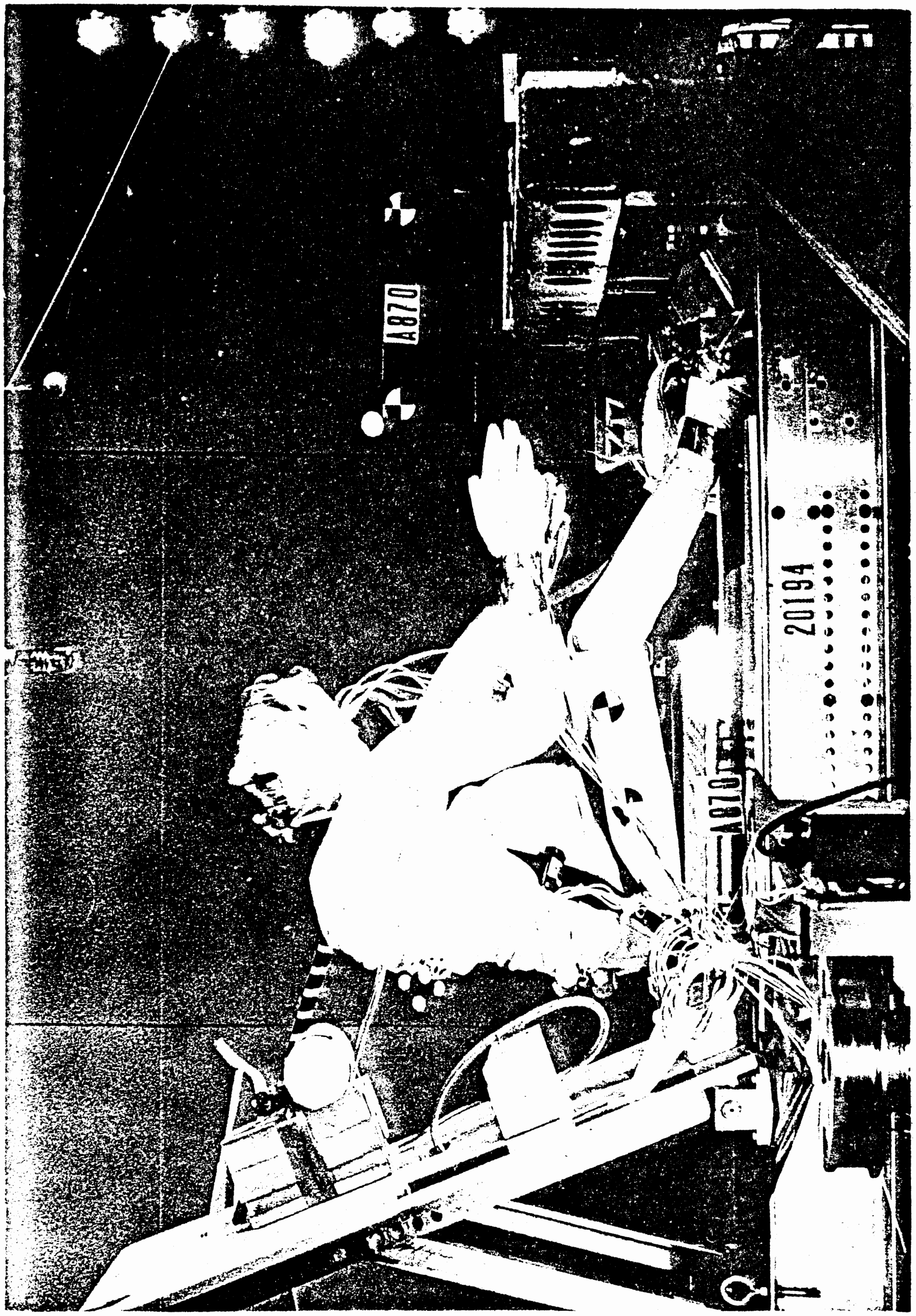
SETUP PHOTOGRAPH: TEST A-870



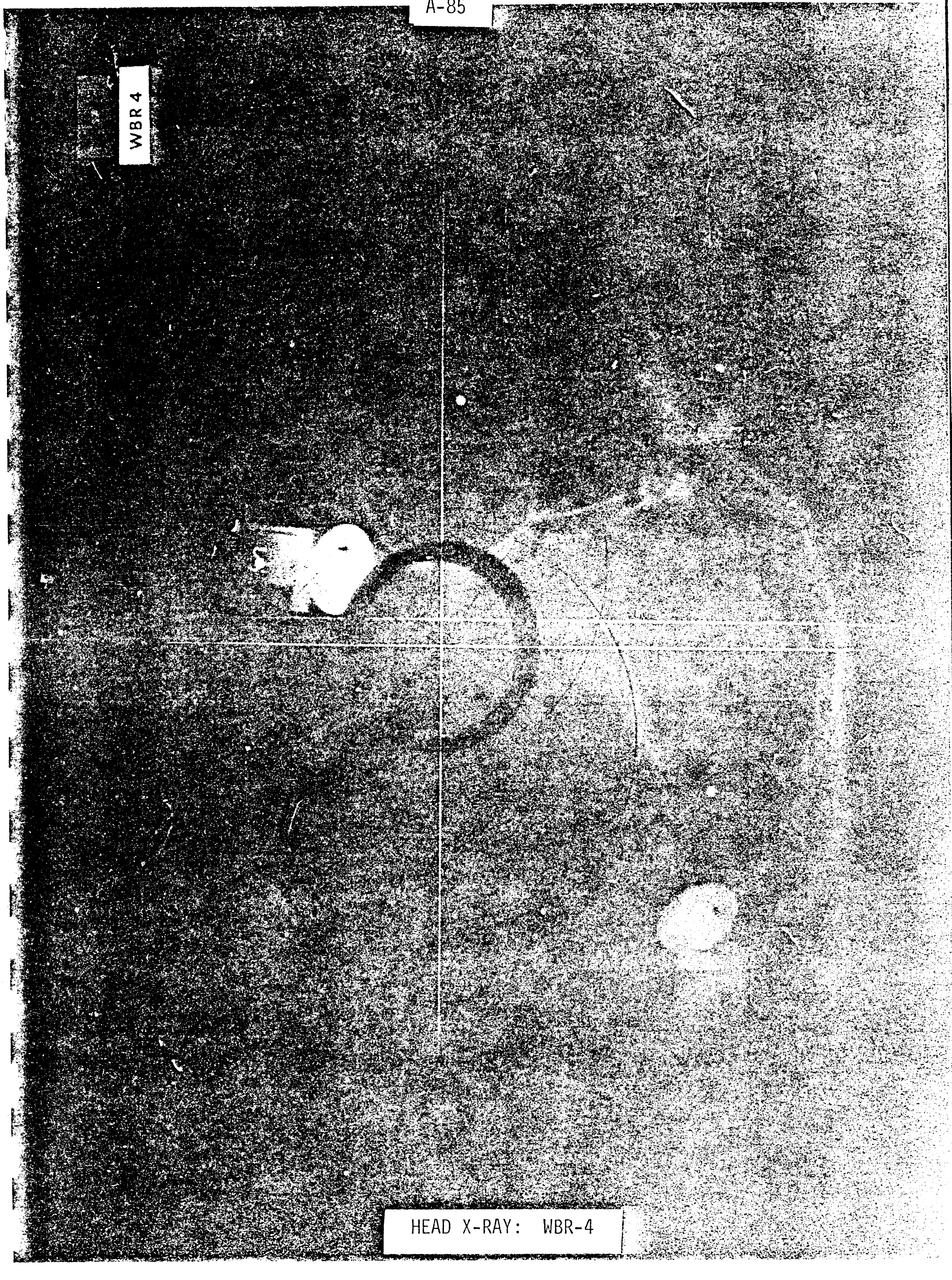
SETUP PHOTOGRAPH: TEST A-870



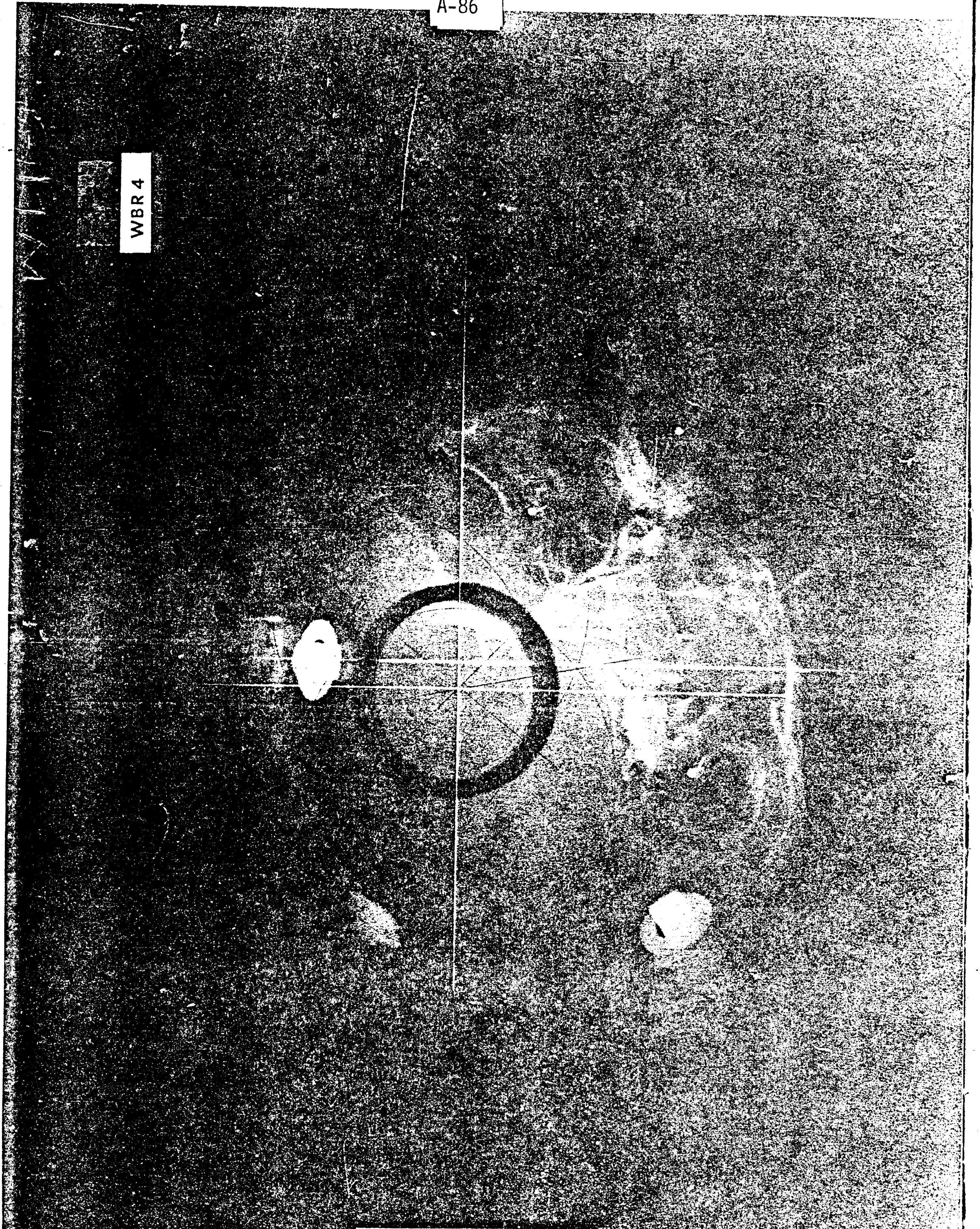
GRAPHCHECK PHOTOGRAPH: TEST A-870



TEST PHOTOGRAPH: WBR-4 TEST A-870



HEAD X-RAY: WBR-4

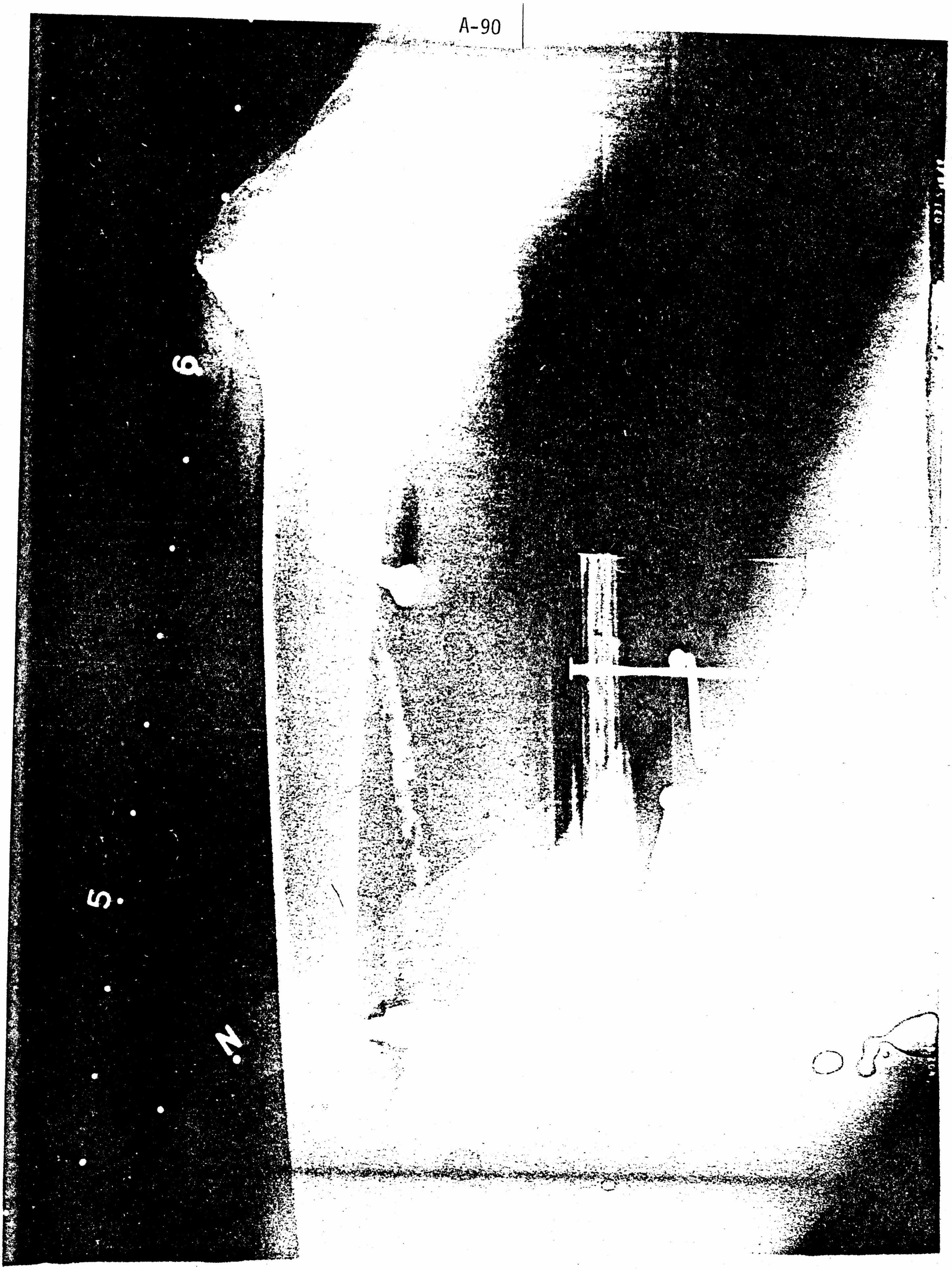


HEAD X-RAY: WBR-4

LATERAL X-RAY: WBR-4

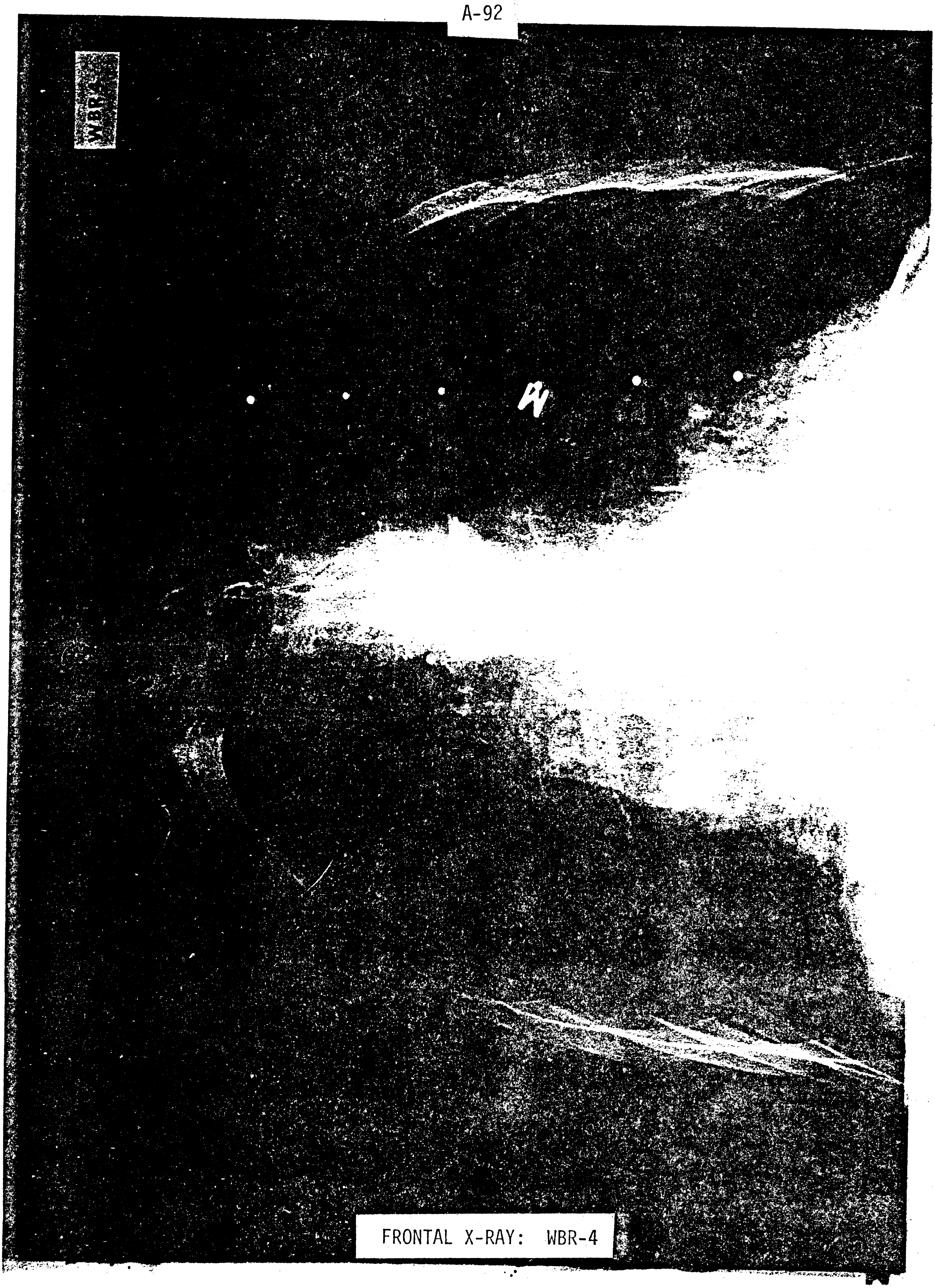
LATERAL X-RAY: WBR-4

LATERAL X-RAY: WBR-4



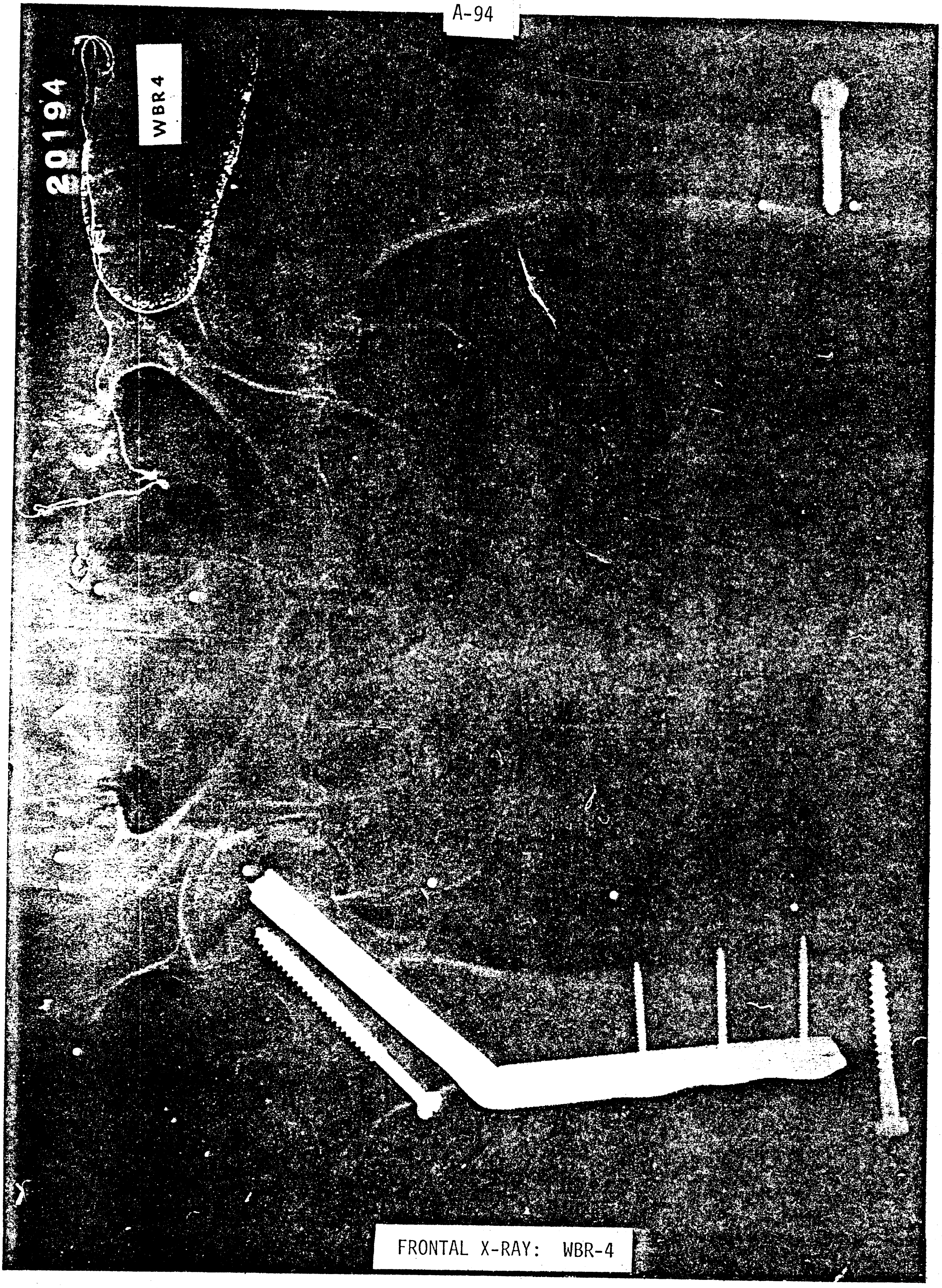
LATERAL X-RAY: WBR-4

LATERAL X-RAY: WBR-4

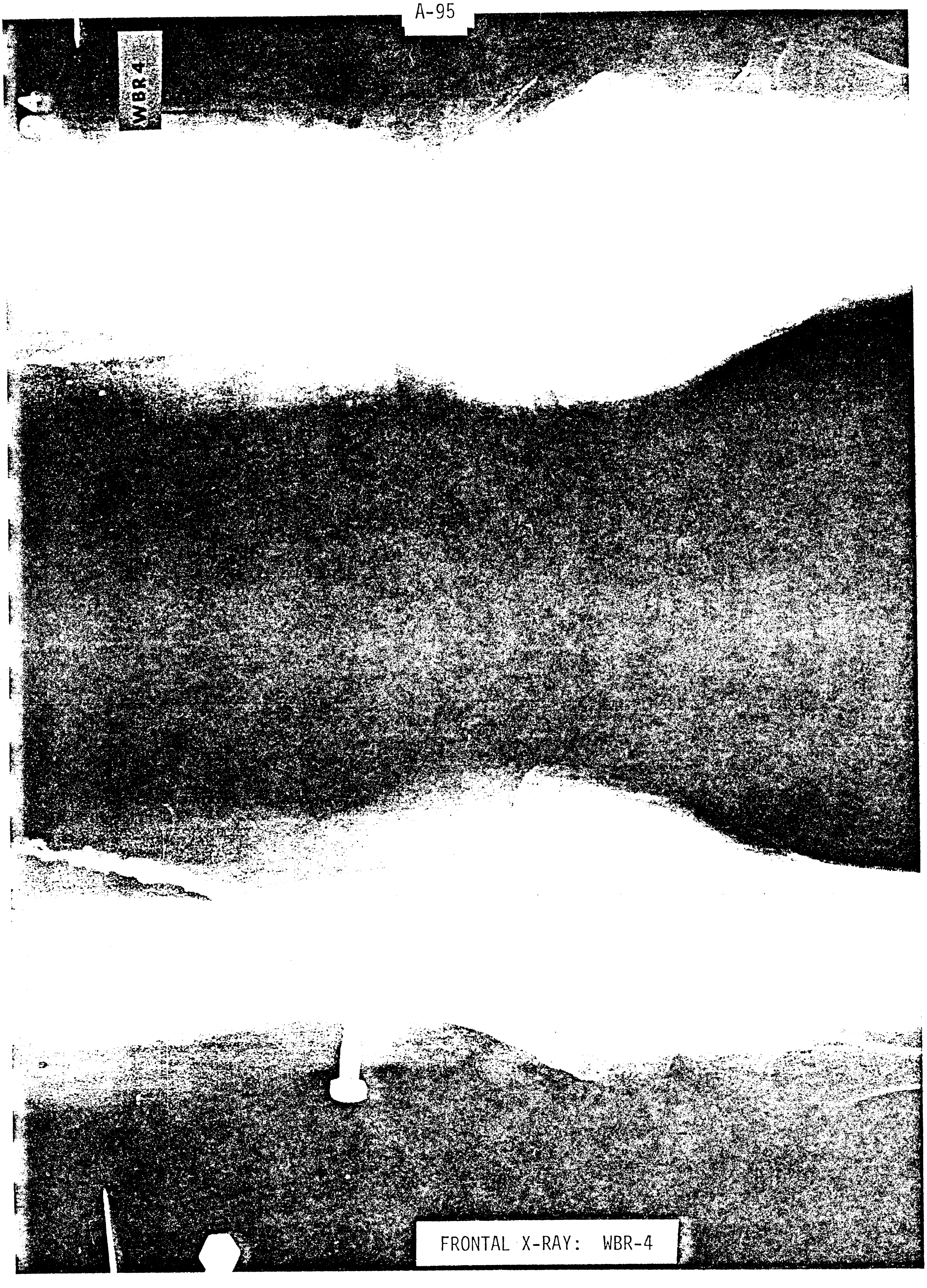


FRONTAL X-RAY: WBR-4

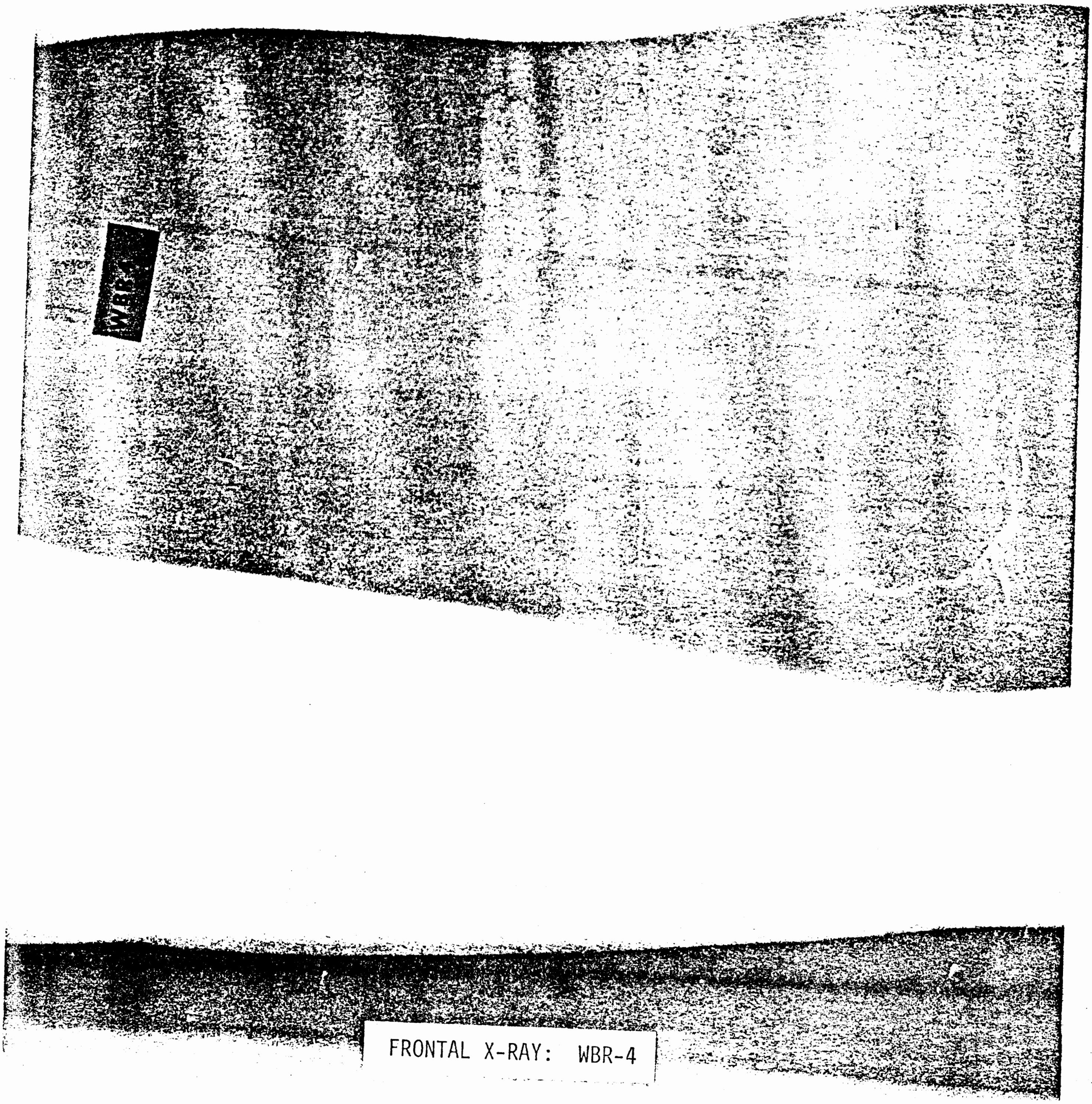
FRONTAL X-RAY: WBR-4



FRONTAL X-RAY: WBR-4



FRONTAL X-RAY: WBR-4



FRONTAL X-RAY: WBR-4

WHOLE BODY RESPONSE

TEST SUMMARY

TEST SERIES WBR-5

TESTS A-874 and A-875

WHOLE BODY RESPONSE

SLED TEST SUMMARY

WBR# 5 DATE 6-17-75

SLED TEST NOS. A-874 AND A-875

TEST SUBJECT DATA

CADAVER ID NO.: 20208 LUNGS PRESSURIZED: No

AGE: 49 years WEIGHT: 185 lbs.

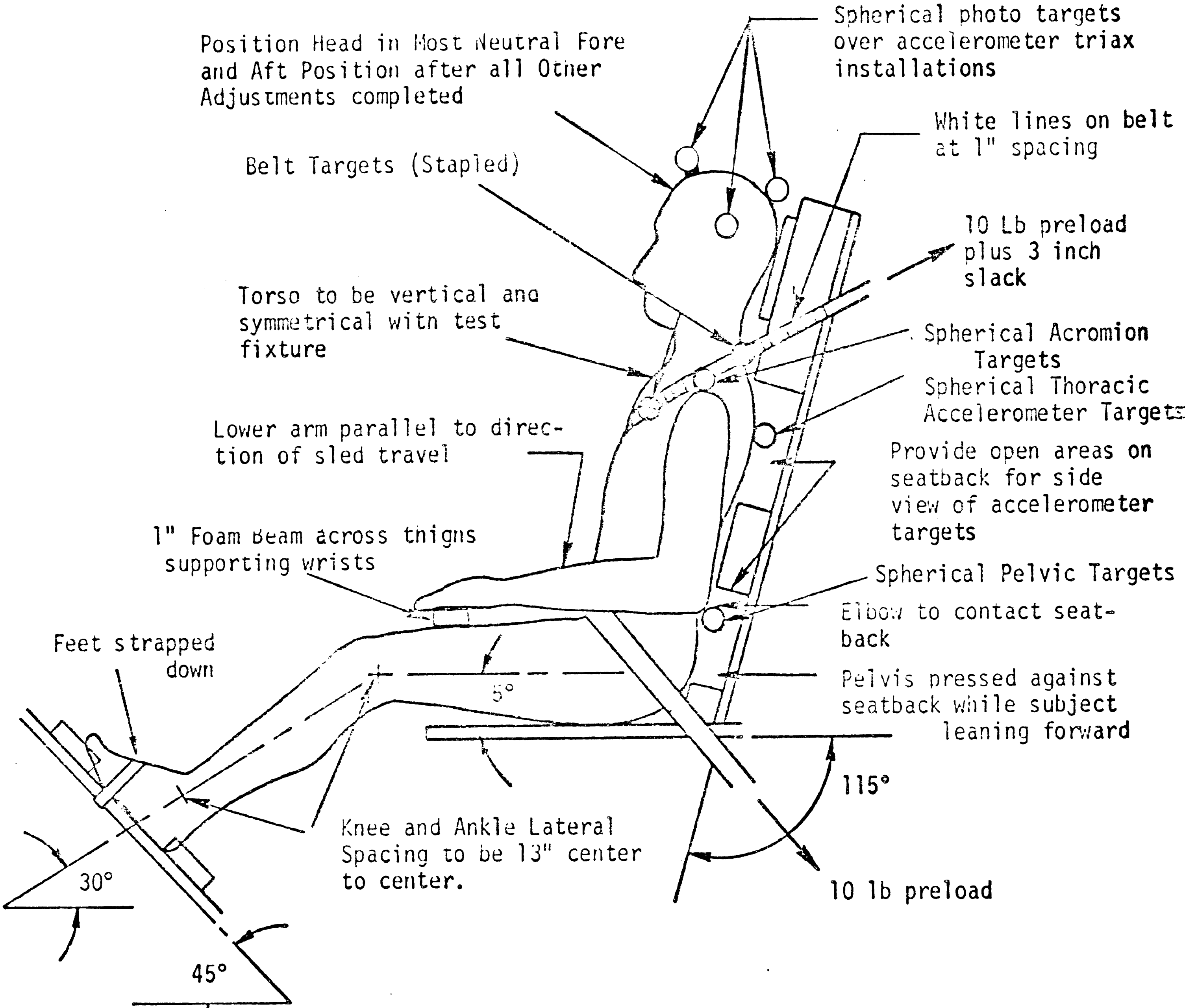
HEIGHT 170.6 cm. SEX: M

TEST PARAMETERS

	FIRST IMPACT	SECOND IMPACT
VELOCITY:	21.7 MPH	22.5 MPH
DECELERATION:	10.2 G's	10.0 G's
IMPACT DIRECTION:	FRONTAL	FRONTAL
RESTRAINT SYSTEM:	3 pt. belt	3 pt. belt

POST IMPACT EVALUATION

	FIRST IMPACT	SECOND IMPACT
a. Test Subject:		
Any Injury		
Submarining	None	None
b. Restraint System		
Damage:	None	None
c. Transducers:		
Any Units Damaged		
Any Units Loosened		
d. Any Data Lost:	None	None



Initial Belt Lengths: R. Lap = 12"
(Center to Center of Ends) L. Lap = 32.5"
Shoulder = 42"

Femur Target Spacing:

Right Side = --- in.

Left Side = ---- in.

POSITIONING AND TARGETING DIAGRAM WBR-5

BELT LENGTH DATA

TEST A- 874

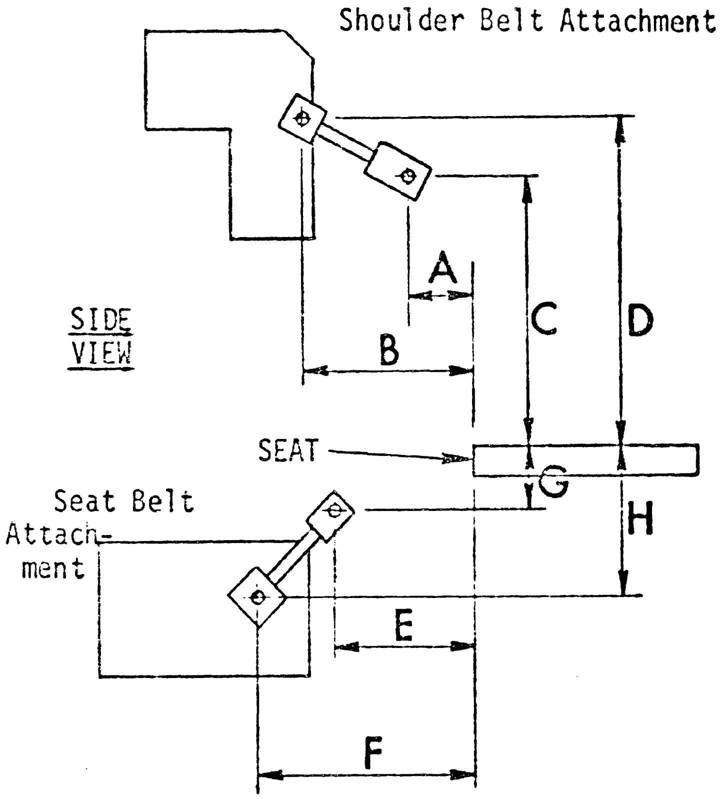
Belt Position	Pre-Impact Length (in)	Post-Impact Length (in)	Belt Stretch (in)	Post-Impact Length with Load Cells
Rt. Lap	12	12	0	11 1/2
Lt. Lap	32 1/2	32 5/8	1/8	32
Shoulder	42	42	0	40 3/8

Test A- 875

Belt Position	Pre-Impact Length (in)	Post-Impact Length (in)	Belt Stretch (in)	Post-Impact Length with Load Cells
Rt. Lap	12	12	0	11 1/4
Lt. Lap	32 1/2	33	1/2	32 1/4
Shoulder	42	42 3/8	3/8	40 3/4

BELT ANCHOR DATA

TEST WBR-5 A-874



SEAT BELT DIMENSIONS

RIGHT SIDE	LEFT SIDE
E = 3 3/4"	E = 3 1/2"
F = 6 3/4"	F = 6 1/2"
G = 5 1/2"	G = 7 1/2"
H = 11 1/2"	H = 11"

Belt Anchor Separations

L = 14 3/4"

M = 15 1/2"

SHOULDER BELT DIMENSIONS

A = 18 1/4"

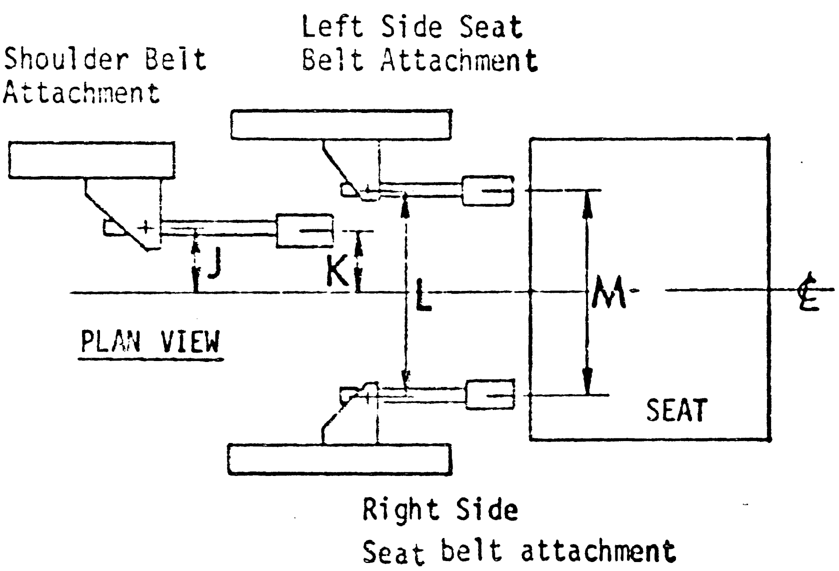
B = 23 3/4"

C = 3 3/4"

D = 7 5/8"

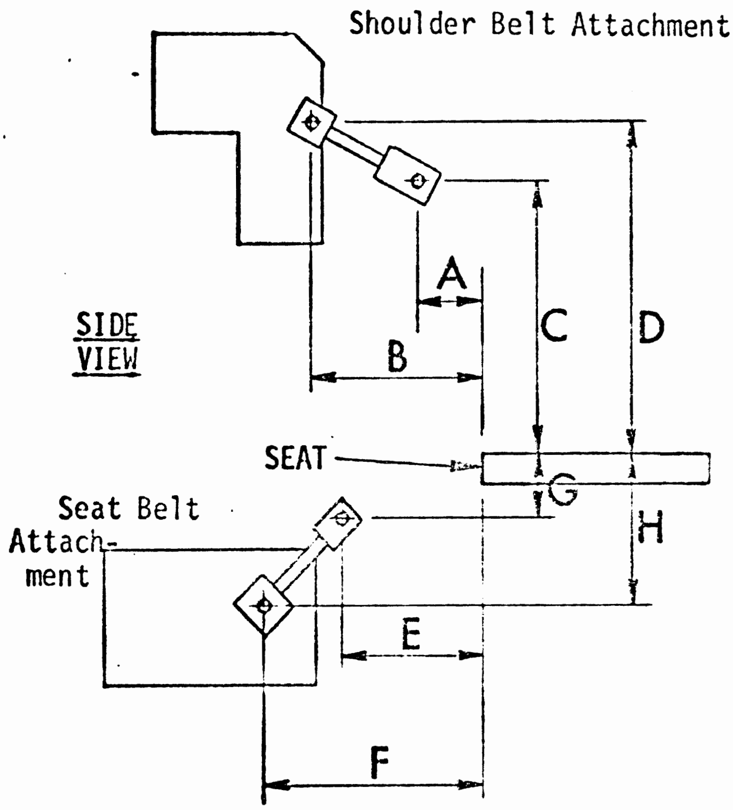
J = 6 7/8"

K = ______



BELT ANCHOR DATA

TEST WBR-5 A-875



SEAT BELT DIMENSIONS

RIGHT SIDE		LEFT SIDE	
E =	3 1/2"	E =	4 1/8"
F =	6 5/8"	F =	6 1/2"
G =	5 7/8"	G =	8 1/4"
H =	1 1/2"	H =	11 1/4"

Belt Anchor Separations

L = 14 3/4"

M = 15"

SHOULDER BELT DIMENSIONS

A = 18 3/4"

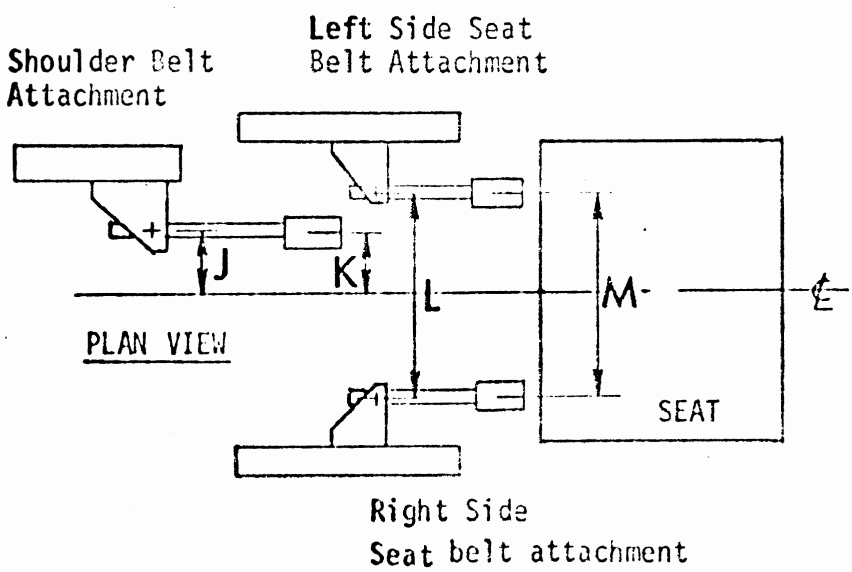
B = 23 5/8"

C = 30 1/8"

D = 32 3/8"

J = 7 1/2"

K = 6 1/4"



INSTRUMENTATION DATA SHEET

TEST NO. WBR-5 SLED RUN NO. A-874; A-875 DATE 6-17-75 PREPARED BY

TAPE DATA: RECORDER Honeywell RECORD SPEED 30 IPS

		TAPE		TRANSDUCER			CALIBRATION						
CHAN.	INPUT	40% (3V) MODULATION VALUE	RUN GAIN	EXCIT. VOLT.	TYPE	S/N	CAL. RESISTOR	CAL. VOLTAGE	CAL. GAIN	CAL. VALUE	+ -	OUTPUT RUN SENSITIVITY	CHAN.
1	Sled Decel		200		Stath	T 3587				22G/ 44G	+	20 G/V	1
2	Head Q- 1 A	-123.6 G	100	10	Endev	AB56	199.3K	-1.17	100	48.2G	-	41.2 G/V	2
3	Head Q- 1 B	-144.6 G	100	10	"	AB59	200.0K	-1.17	100	56.4G	-	48.2 G/V	3
4	Head Q- 1 C	-125.4 G	100	10	"	AB60	199.6K	-1.16	100	48.5G	-	41.8 G/V	4
5	Head Q- 2 C	-167.4 G	100	10	"	AB61	199.4K	-1.18	100	65.8G	-	55.8 G/V	5
6	Head Q- 2 A	-119.4 G	100	10	"	AB79	199.4K	-1.32	100	52.5G	-	39.8 G/V	6
7	Head Q- 2 B	-141.6 G	100	10	"	AB85	199.5K	-1.16	100	54.8G	-	47.2 G/V	7
8	Head Q- 3 B	-120.0 G	100	10	"	AB87	199.5K	-1.16	100	46.4G	-	40.0 G/V	8
9	Head Q- 3 C	-129.6 G	100	10	"	AB90	199.6K	-1.15	100	49.7G	-	43.2 G/V	9
10	Head Q- 3 A	-132.9 G	100	10	"	AB97	199.4K	-1.16	100	51.4G	-	44.3 G/V	10
11													11
12	Velocity Pulse		10									12"/Pulse	12
13	Dig. Gate	25/28											13
14	Time Base											.01 sec/ pulse	14

INSTRUMENTATION DATA SHEET

TEST NO. WBR-5 SLED RUN NO. A-874; A-875 DATE 6-17-75 PREPARED BY

TAPE DATA: RECORDER CEC : RECORD SPEED 30 IPS

	TAPE			TRANSDUCER			CALIBRATION						
CHAN.	INPUT	40% (3V) MODULATION VALUE	RUN GAIN	EXCIT. VOLT.	TYPE	S/N	CAL. RESISTOR	CAL. VOLTAGE	CAL. GAIN	CAL. VALUE	±	OUTPUT RUN SENSITIVITY	CHAN.
1	Sled Decel.		200		Stath	13587				22G/ 44G	+	20 G/V	1
2	Pelvis P-A	150.6 G	100	10	Endev	AC04	199.4K	-1.17	100	58.7G		50.2 G/V	2
3	Pelvis I-S	-138.3 G	100	10	"	AC06	199.5K	-1.26	100	58.1G		46.1 G/V	3
4	Thorax P-A	210.9 G	100	10	Entrn	112Y	102.3	+ .846	100	59.5G		70.3 G/V	4
5	Thorax I-S	220.5 G	100	10	"	112X	102.3	+ .679	100	49.9G		73.5 G/V	5
6	Thorax R-L	227.4 G	100	10	"	910X	102.5	- .830	100	62.9G		75.8 G/V	6
7	Rt. Lap	3012.3#	200	-	G.S.E	082	50 K	+2.20	200	2209#	+	1004.1 #/V	7
8	Lt. Lap	3002.7#	200	-	"	083	50 K	+2.24	200	2242#	+	1000.9 #/V	8
9	Up. Shldr.	3009.3#	VAR	-	"	084	50 K	+2.27	-	2277#	+	1003.1 #/V	9
10	Low Shldr.	2466.9#	VAR	-	"	085	50 K	+2.73	-	2245#	+	822.3 #/V	10
11													11
12	Velocity		10									Fourth pulse is T_o	12
13	Dig. Gate	25/28											13
14	Time Base												14

HEAD X-RAY DATA SHEET

WHOLE BODY RESPONSE PROJECT

WBR NO. 5

TARGET		INSTALLATION FIXTURE DIMENSION	DISTANCE FROM X-RAY PLANE: X-Z PLANE (Side view)	DISTANCE FROM X-RAY PLANE: Y-Z PLANE (Frontal)
ACCELEROMETERS				
Location	Name			
Collet Furthest to Right-Rear of Head	Q_1	3.148	11.25	13.5
Next Collet clockwise from Q_1 (viewed from top)	Q_2	4.463	6.0	14.25
Next Collet clockwise from Q_2 (viewed from top)	Q_3	4.135	9.0	16.5
ANATOMICAL MARKER PELLETS				
Right Eye	□		8.0	21.5
Left Eye			6.0	20.25
Right Ear	○		11.5	19.25
Left Ear			6.5	15.5

X-RAY DATA	X-Z PLANE	Y-Z PLANE
VOLTAGE	90 KVP	90 KVP
CURRENT	100 mA	100 mA
TIME	.4	.4
SATISFACTORY? (Check if Yes)	✓	✓

Sketch of Relative Positions of Accelerometer Targets As Viewed from X-Ray Source.

X-Z PLANE (Side view)	Y-Z PLANE (Frontal)
Q3	Q3
Q2	Q2
Q1	Q1

WHOLE BODY RESPONSE: ANTHROPOMETRY

CADAVER ID: 20208

DATE: 6/13/75

ANTHROPOMETRIST: H. M. Reynolds

Anthropometric Measurements:

(A = Anthropometer; Sp. C. = Spreading Calipers; Sl. C. = sliding calipers; T = Tapes)

1.	Weight		185. Lbs
2.	Stature (A)		170.4 cm
3.	Trochanterion Hgt. (A)	Rt.	82.9
		Lt.	83.1
4.	Anterior-Superior Iliac Spine Hgt. (A)	Rt.	77.7
		Lt.	78.2
5.	Iliocristale Hgt. (A)	Rt.	72.8
		Lt.	73.0
6.	Substernale Hgt. (A)		48.6
7.	Axilla Hgt. (A)		
8.	Suprasternale Hgt. (A)		27.4
9.	Nipple Hgt. (A)		
10.	Mastoid Hgt. (A)		16.7
11.	Nuchale Hgt. (A)		12.7
12.	Tragion Hgt. (A)	Rt.	12.9
		Lt.	12.6
13.	Menton Hgt. (A)		24.1
14.	Head Breadth (Sp. C.)		15.1
15.	Head Length (Sp. C.)		19.9

Cad. I.D. 20208

16.	Bitragion Diameter (Sp. C.)	14.1
17.	Bigonial Diameter (Sp. C.)	9.9
18.	Menton Diagonal (Sp. C.)	26.3
19.	Mastoid Diagonal (A)	17.2
20.	Head Circumference (T)	57.2
21.	Mid-Sagittal Arc Length (T)	36.5
22.	Coronal Arc Length (T)	36.3
23.	Mid-Neck Circumference (T)	40.6
24.	Chest Circumference at Axilla (T)	
25.	Chest Circumference at Nipple (T)	94.9
26.	Chest Circumference at Substernale (T)	104.0
27.	Hip Circumference, Iliocristale (T)	99.4
28.	Buttocks Circumference, Trochanterion (T)	96.8
29.	Upper Arm Circumference, Axilla (T)	29.5
30.	Upper Arm Circumference, Mid Biceps (T)	30.1
31.	Upper Arm Circumference, Humeral Condyles (T)	25.2
32.	Maximum Forearm Circumference (T)	27.2
33.	Wrist Circumference (T)	16.3
34.	Upper Thigh Circumference (T)	52.7
35.	Mid-Thigh Circumference (T)	52.7
36.	Lower Thigh Circumference (T)	41.8
37.	Maximum Calf Circumference (T)	37.2
38.	Ankle Circumference (T)	23.2

Cad. I.D. 20208

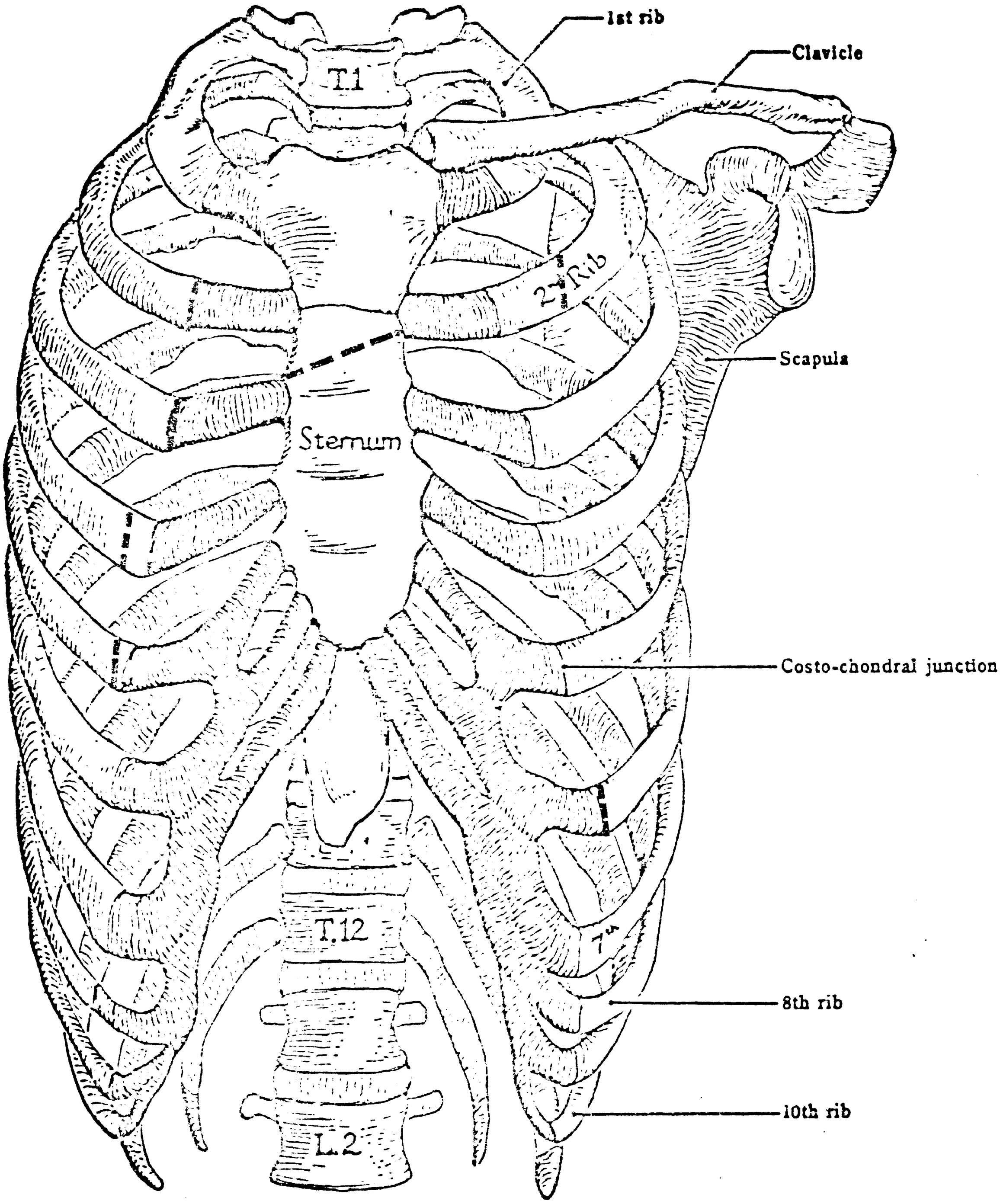
39.	Biacromial Diameter (A)		35.0
40.	Bideltoid Breadtn (A)		45.9
41.	Chest Breadth at Axilla (A)		
42.	Chest Breadth at Mid-Point between Suprasternale and Substernale		29.1
43.	Chest Breadth at Substernale (A)		31.9
44.	Hip Breadth, Iliocristale (A)		26.1
45.	Bispinous Diameter (A)		23.1
46.	ASIS to Symphysion Distance (A)	Rt.	15.3
		Lt.	13.9
47.	Bitrochanteric Diameter (A)		33.1
48.	Chest Depth at Suprasternale (A)		17.3
49.	Chest Depth at Axilla (A)		
50.	Chest Depth at Nipple (A)		22.3
51.	Chest Depth at Substernale (A)		24.4
52.	Hip Depth, Iliocristale (A)		27.0
53.	ASIS Depth (A)	Rt.	16.4
		Lt.	20.9
54.	Buttocks Depth, Trochanterion (A)		
55.	Trochanterion	Rt.	
		Lt.	
56.	Symphysion (Hgt.)		
57.	Acromion-Radiale Length		31.1

Cad. I.D. 20208

58.	Ball of Humerus - Radiale Length (A)	28.4
59.	Radiale-Stylion Length (A)	24.8
60.	Olecronan-Stylion Length (A)	27.6
61.	Femur Length (A)	39.8
62.	Tibia Length (A)	41.0
63.	Fibula Length (A)	
64.	Upper Arm Depth, Mid Biceps (S1.C.)	11.6
65.	Humeral Biepicondylar Breadth (S1.C.)	7.0
66.	Forearm Depth (S1.C.)	8.3
67.	Wrist Depth (S1.C.)	6.6
68.	Hand Length (S1.C.)	17.2
69.	Hand Breadth (S1.C.)	8.1
70.	Hand Depth (S1.C.)	2.5
71.	Thigh Breadth, Mid-Thigh (S1.C,)	15.2
72.	Calf Depth (S1.C.)	9.3
73.	Bimalleolus Breadth (S1. C.)	6.8
74.	Foot Length (S1.C.)	23.7
75.	Foot Breadth (S1.C.)	9.6

WHOLE BODY RESPONSE - WBR # 5

AUTOPSY RESULTS



Bony Thorax, anterior aspect

RIB FRACTURE SITES ARE INDICATED BY DASHED LINES (-----)

OTHER INJURIES:

The Acromial articular surface was dislocated.
The Humerus head was dislocated.

TAPE: GMR-F1

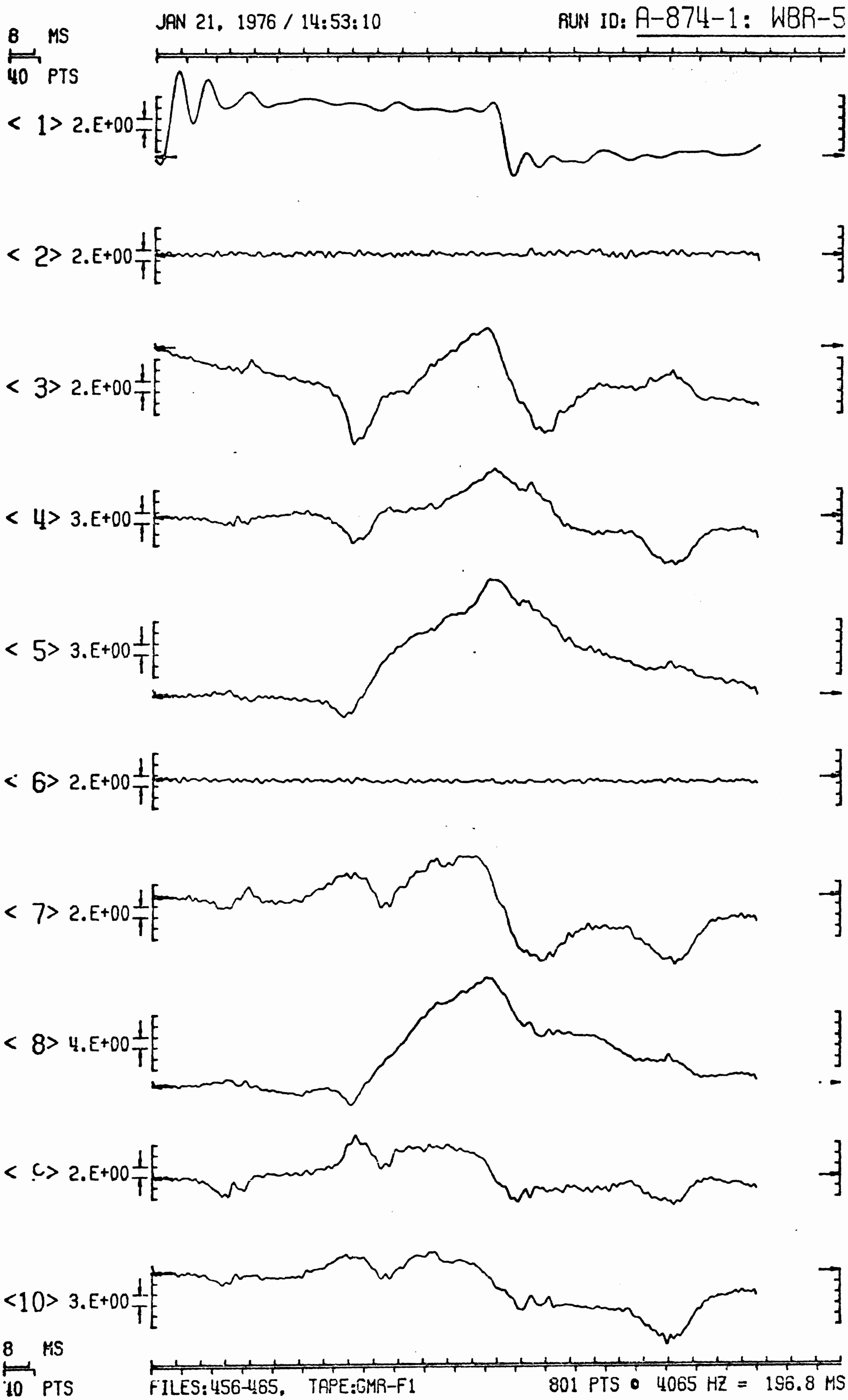
DIGITAL SIGNAL FILTERING
JAN 21, 1976 03:18:50

RUN ID: A-874-1: WBR-5

PROJECT: WHOLE BODY RESPONSE: CADAVER WBR-3 (9-ACC)

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
456 -	1:	SLED DECELERATION	G'S	801	4065.	LP(015-045)	(1)
457 -	2:	AX1 HEAD ACC (A)	G'S	801	4065.	LP(090-130)	(3)
458 -	3:	AY1 HEAD ACC (B)	G'S	801	4065.	LP(090-130)	(3)
459 -	4:	AZ1 HEAD ACC (C)	G'S	801	4065.	LP(090-130)	(3)
460 -	5:	AX2 HEAD ACC (C)	G'S	801	4065.	LP(090-130)	(3)
461 -	6:	AY2 HEAD ACC (A)	G'S	801	4065.	LP(090-130)	(3)
462 -	7:	AZ2 HEAD ACC (B)	G'S	801	4065.	LP(090-130)	(3)
463 -	8:	AX3 HEAD ACC (B)	G'S	801	4065.	LP(090-130)	(3)
464 -	9:	AY3 HEAD ACC (C)	G'S	801	4065.	LP(090-130)	(3)
465 -	10:	AZ3 HEAD ACC (A)	G'S	801	4065.	LP(090-130)	(3)
	11:						
	12:						

FILES: 456 - 465 ON TAPE: GMR-F1 RUN: A-874-1: WBR-5 FILTERED JAN 21, 1976 03:19:22


JAN 21, 1976 / 14:53:10
RUN ID: A-874-1: WBR-5
8 MS
40 PTS
< 1> 2.E+00
< 2> 2.E+00
< 3> 2.E+00
< 4> 3.E+00
< 5> 3.E+00
< 6> 2.E+00
< 7> 2.E+00
< 8> 4.E+00
< 9> 2.E+00
<10> 3.E+00
8 MS
40 PTS
FILES:456-465, TAPE:GMR-F1
801 PTS @ 4065 HZ = 196.8 MS

TAPE: GMR-F1

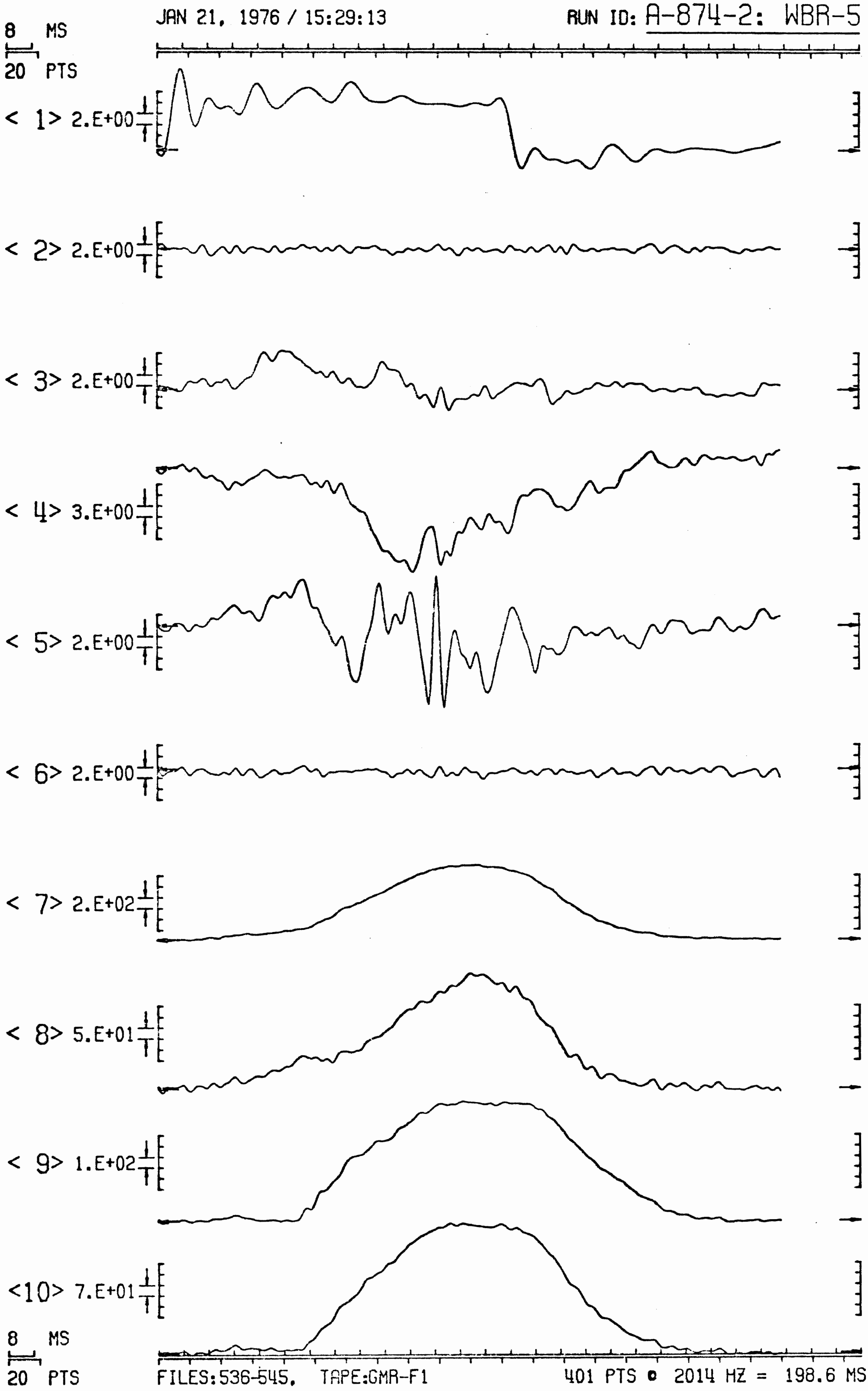
DIGITAL SIGNAL FILTERING
JAN 21, 1976 03:32:26

RUN ID: A-874-2: WBR-5

PROJECT: WHOLE BODY RESPONSE.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
536 -	1:	SLED DECELERATION	G'S	401	2015.	LP(030-090)	(4)
537 -	2:	PELVIS BIAX P-A ACC	G'S	401	2015.	LP(090-225)	(5)
538 -	3:	PELVIS BIAX I-S ACC	G'S	401	2015.	LP(090-225)	(5)
539 -	4:	THORAX TRIAX P-A ACC	G'S	401	2015.	LP(090-225)	(5)
540 -	5:	THORAX TRIAX I-S ACC	G'S	401	2015.	LP(090-225)	(5)
541 -	6:	THORAX TRIAX R-L ACC	G'S	401	2015.	LP(090-225)	(5)
542 -	7:	RIGHT LAP BELT LOAD	LBS	401	2015.	LP(090-225)	(5)
543 -	8:	LEFT LAP BELT LOAD	LBS	401	2015.	LP(090-225)	(5)
544 -	9:	UPPER SHOULDER BELT LOAD	LBS	401	2015.	LP(090-225)	(5)
545 -	10:	LOWER SHOULDER BELT LOAD	LBS	401	2015.	LP(090-225)	(5)
	11:						
	12:						

FILES: 536 - 545 ON TAPE: GMR-F1 RUN: A-874-2: WBR-5 FILTERED JAN 21, 1976 03:32:59

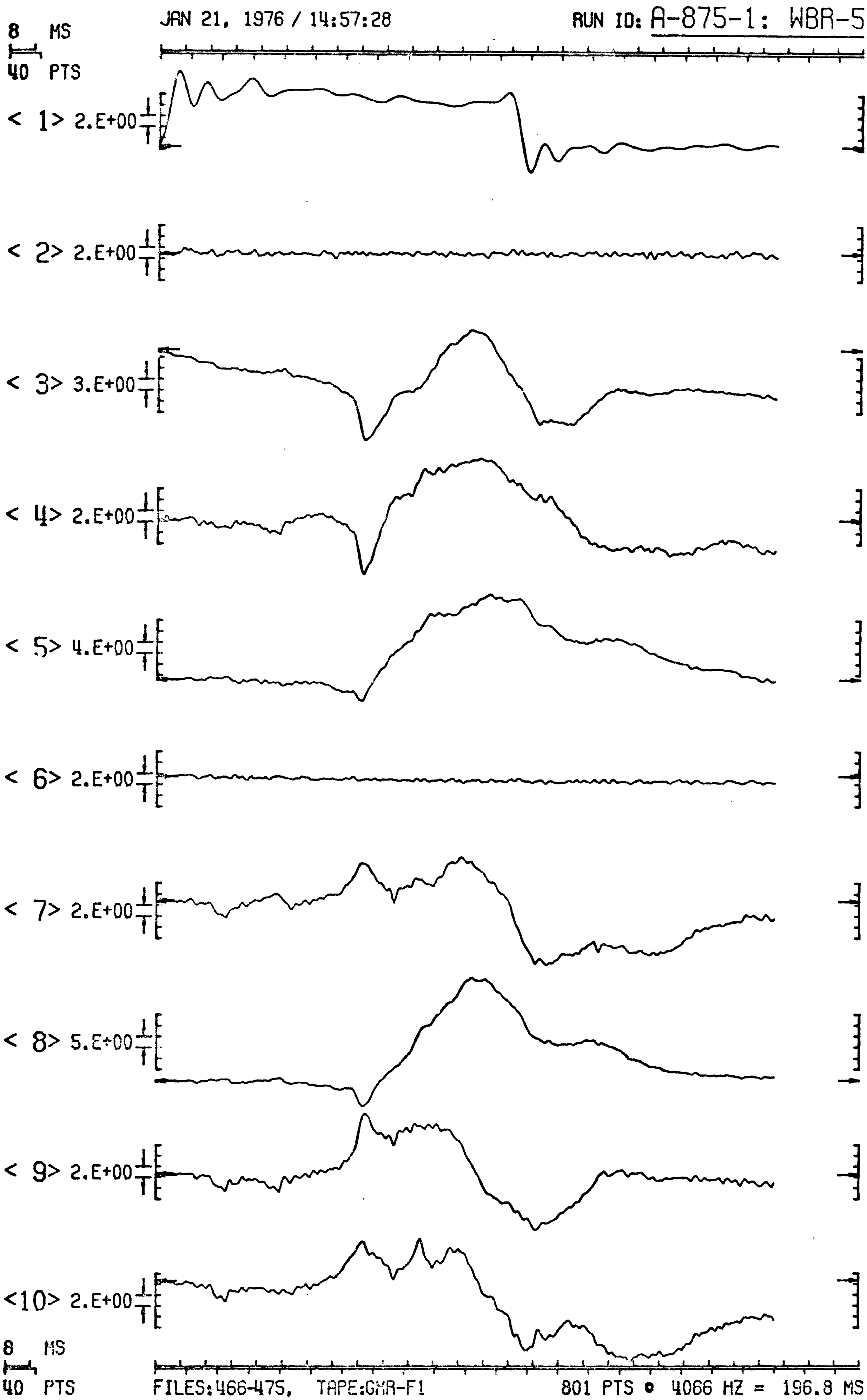

JAN 21, 1976 / 15:29:13
RUN ID: A-874-2: WBR-5
8 MS
20 PTS
< 1> 2.E+00
< 2> 2.E+00
< 3> 2.E+00
< 4> 3.E+00
< 5> 2.E+00
< 6> 2.E+00
< 7> 2.E+02
< 8> 5.E+01
< 9> 1.E+02
<10> 7.E+01
8 MS
20 PTS
FILES:536-545, TAPE:GMR-F1
401 PTS @ 2014 HZ = 198.6 MS

TAPE: GMR-F1 | DIGITAL SIGNAL FILTERING JAN 21, 1976 03:20:23 | RUN ID: A-875-1: WBR-5

PROJECT: WHOLE BODY RESPONSE: CADAVER WBR-3 (9-ACC)

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
466 -	1:	SLED DECELERATION	G'S	801	4066.	LP(015-345)	(1)
467 -	2:	AX1 HEAD ACC (A)	G'S	801	4066.	LP(090-130)	(3)
468 -	3:	AY1 HEAD ACC (B)	G'S	801	4066.	LP(090-130)	(3)
469 -	4:	AZ1 HEAD ACC (C)	G'S	801	4066.	LP(090-130)	(3)
470 -	5:	AX2 HEAD ACC (C)	G'S	801	4066.	LP(090-130)	(3)
471 -	6:	AY2 HEAD ACC (A)	G'S	801	4066.	LP(090-130)	(3)
472 -	7:	AZ2 HEAD ACC (B)	G'S	801	4066.	LP(090-130)	(3)
473 -	8:	AX3 HEAD ACC (B)	G'S	801	4066.	LP(090-130)	(3)
474 -	9:	AY3 HEAD ACC (C)	G'S	801	4066.	LP(090-130)	(3)
475 -	10:	AZ3 HEAD ACC (A)	G'S	801	4066.	LP(090-130)	(3)
	11:						
	12:						

FILES: 466 - 475 ON TAPE: GMR-F1 RUN: A-875-1: WBR-5 FILTERED JAN 21, 1976 03:20:56

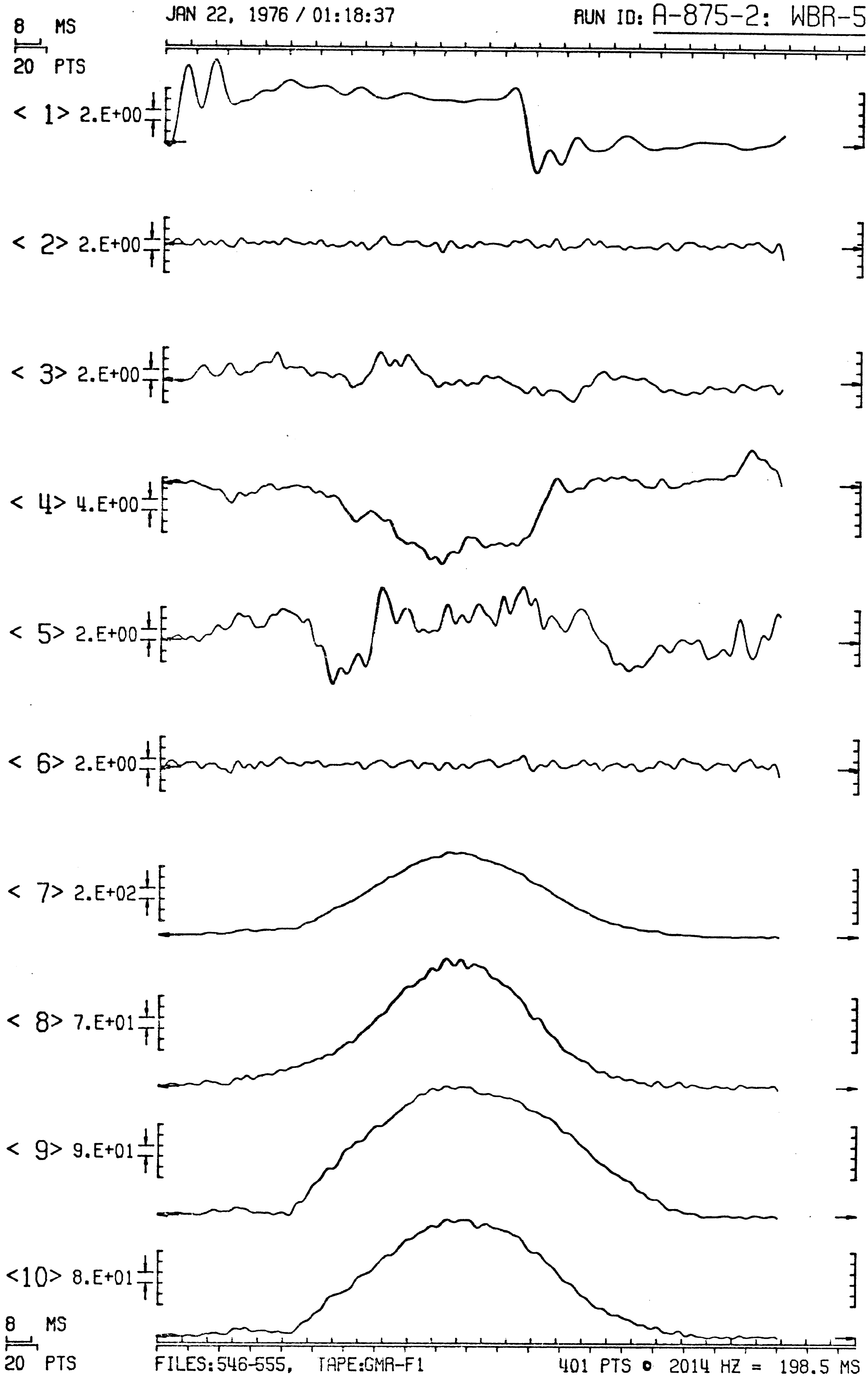

JAN 21, 1976 / 14:57:28
RUN ID: A-875-1: WBR-5
8 MS
40 PTS
< 1> 2.E+00
< 2> 2.E+00
< 3> 3.E+00
< 4> 2.E+00
< 5> 4.E+00
< 6> 2.E+00
< 7> 2.E+00
< 8> 5.E+00
< 9> 2.E+00
<10> 2.E+00
8 MS
40 PTS
FILES:466-475, TAPE:GMR-F1
801 PTS @ 4066 HZ = 196.8 MS

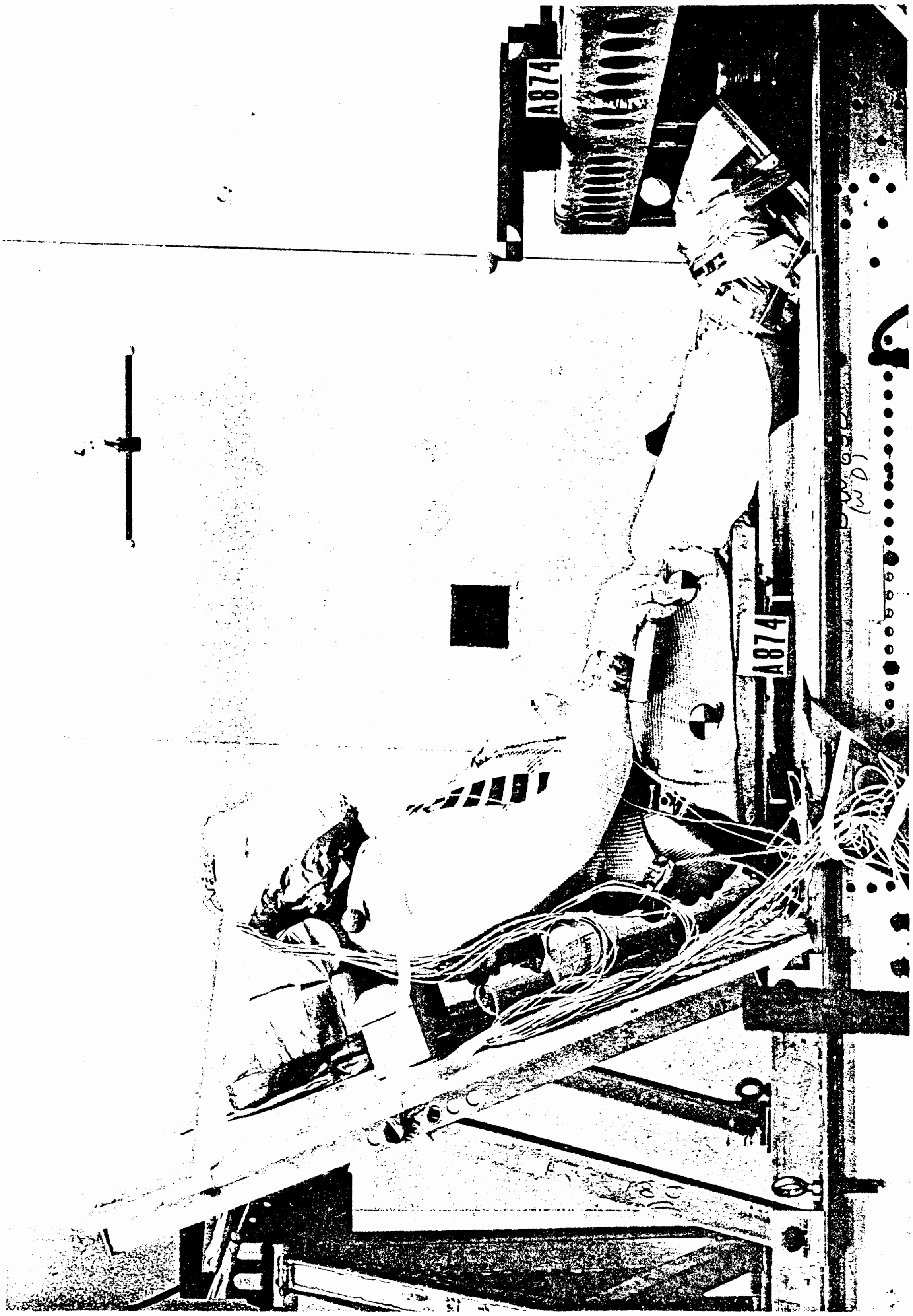
TAPE: GMR-F1	DIGITAL SIGNAL FILTERING JAN 21, 1976 03:33:52	RUN ID: A-875-2: WBR-5

PROJECT: WHOLE BODY RESPONSE.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
546 -	1:	SLED DECELERATION	G'S	401	2015.	LP(030-[illegible])	(4)
547 -	2:	PELVIS BIAX P-A ACC	G'S	401	2015.	LP(090-225)	(5)
548 -	3:	PELVIS BIAX I-S ACC	G'S	401	2015.	LP(090-225)	(5)
549 -	4:	THORAX TRIAX P-A ACC	G'S	401	2015.	LP(090-225)	(5)
550 -	5:	THORAX TRIAX I-S ACC	G'S	401	2015.	LP(090-225)	(5)
551 -	6:	THORAX TRIAX R-L ACC	G'S	401	2015.	LP(090-225)	(5)
552 -	7:	RIGHT LAP BELT LOAD	LBS	401	2015.	LP(090-225)	(5)
553 -	8:	LEFT LAP BELT LOAD	LBS	401	2015.	LP(090-225)	(5)
554 -	9:	UPPER SHOULDER BELT LOAD	LBS	401	2015.	LP(090-225)	(5)
555 -	10:	LOWER SHOULDER BELT LOAD	LBS	401	2015.	LP(090-225)	(5)
	11:						
	12:						

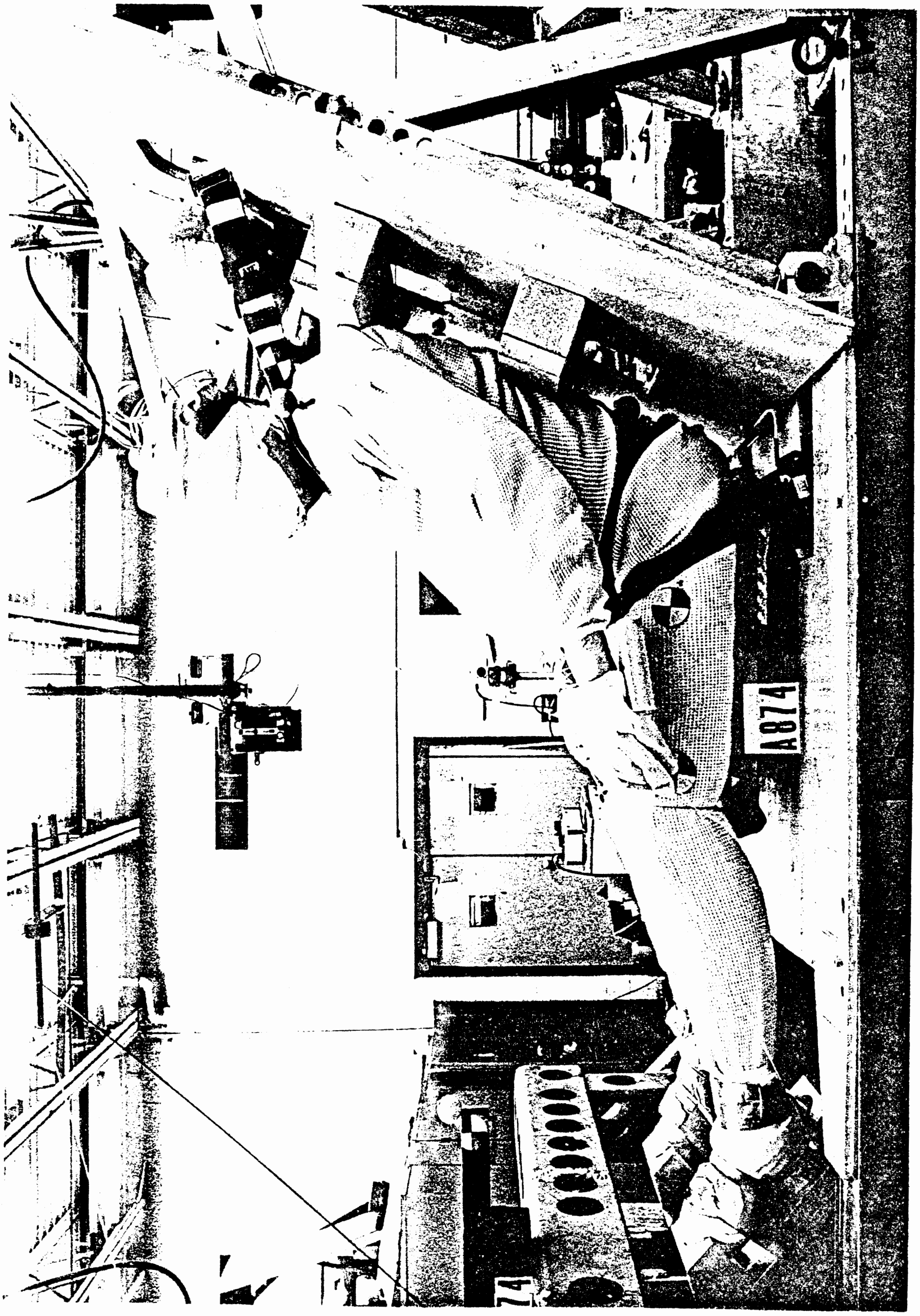
FILES: 546 - 555 ON TAPE: GMR-F1 RUN: A-875-2: WBR-5 FILTERED JAN 21, 1976 03:34:25


JAN 22, 1976 / 01:18:37
RUN ID: A-875-2: WBR-5
8 MS
20 PTS
< 1> 2.E+00
< 2> 2.E+00
< 3> 2.E+00
< 4> 4.E+00
< 5> 2.E+00
< 6> 2.E+00
< 7> 2.E+02
< 8> 7.E+01
< 9> 9.E+01
<10> 8.E+01
8 MS
20 PTS
FILES:546-555, TAPE:GMR-F1
401 PTS @ 2014 HZ = 198.5 MS

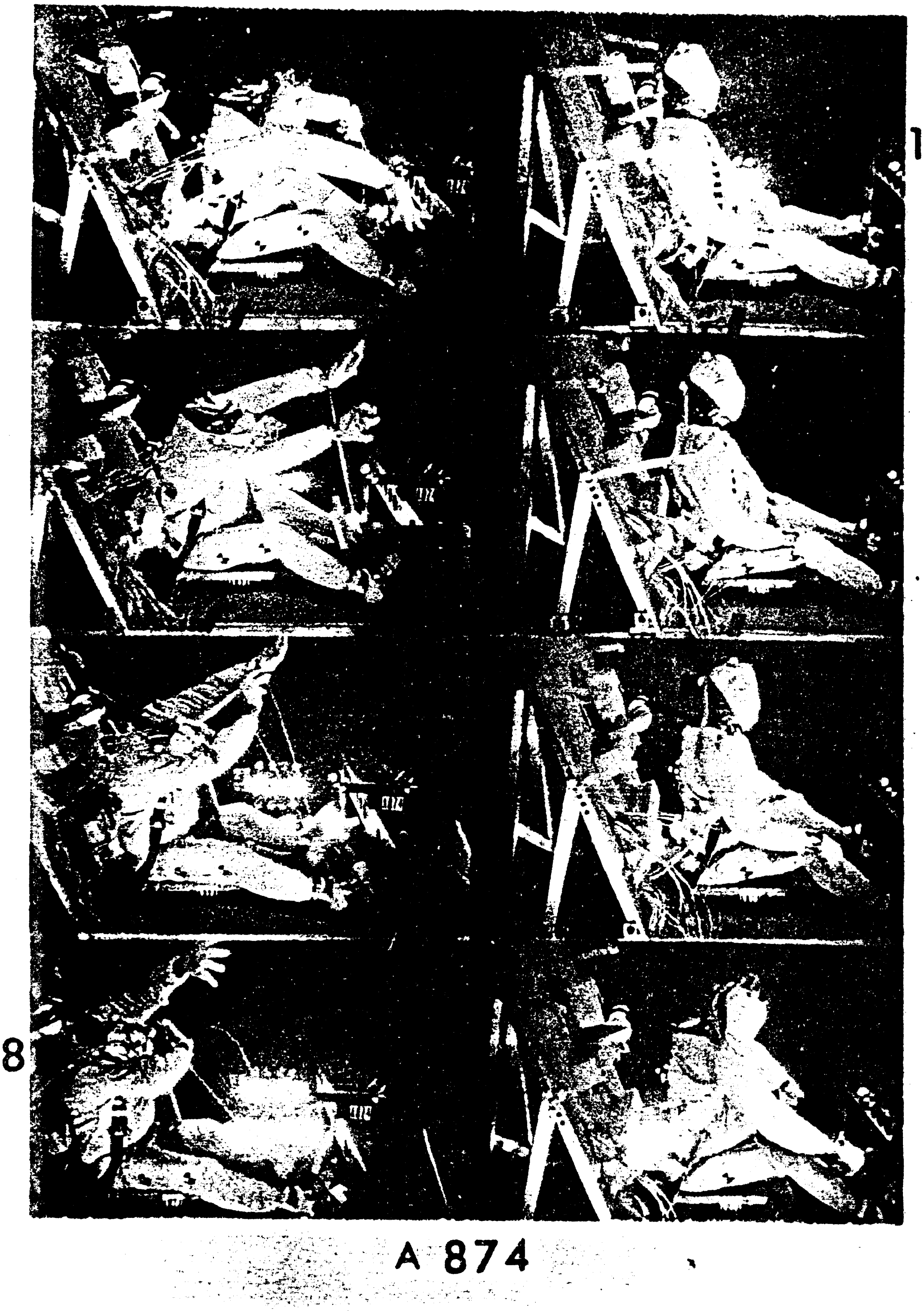


SETUP PHOTOGRAPH: TEST A-874

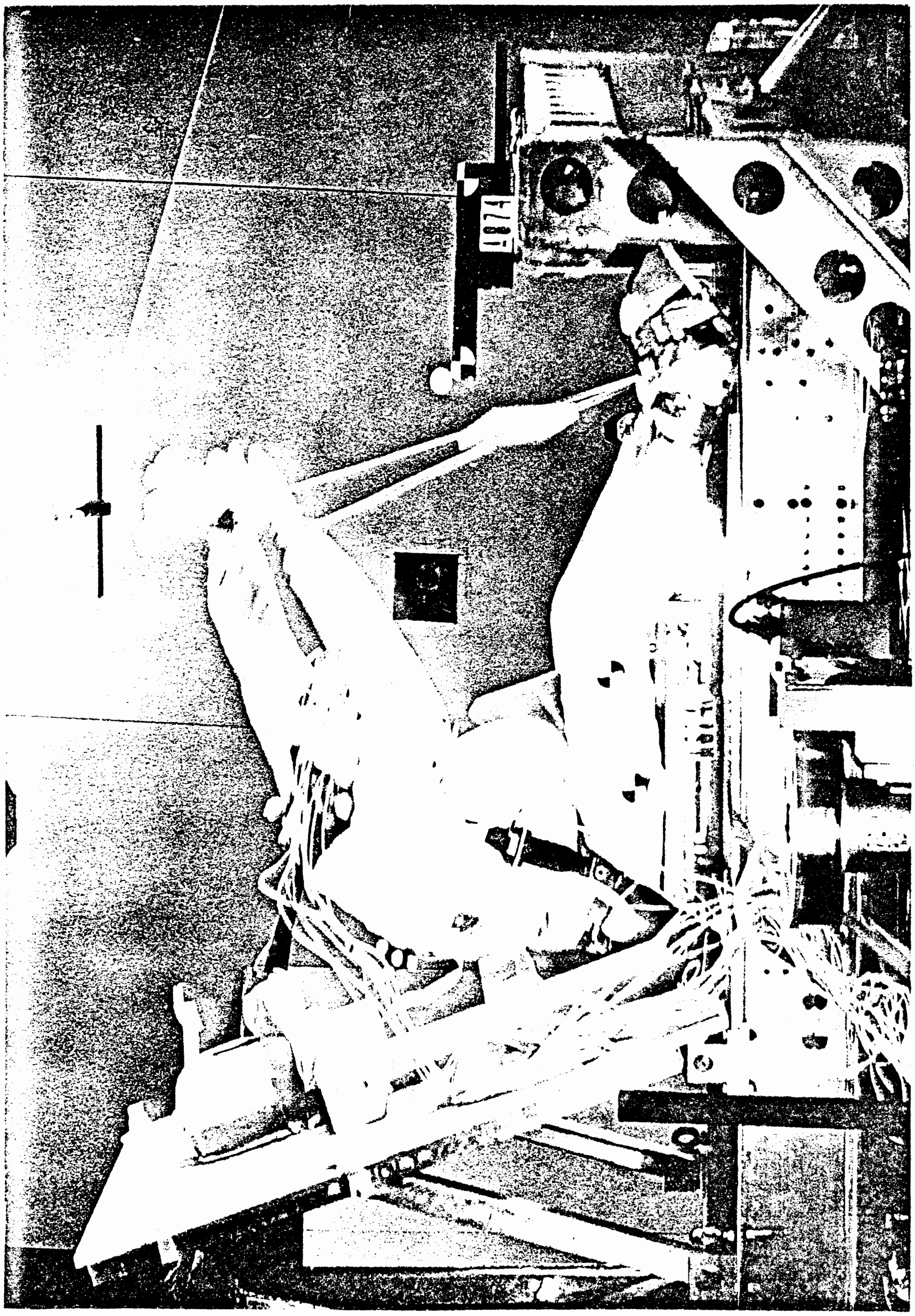
SETUP PHOTOGRAPH: TEST A-874



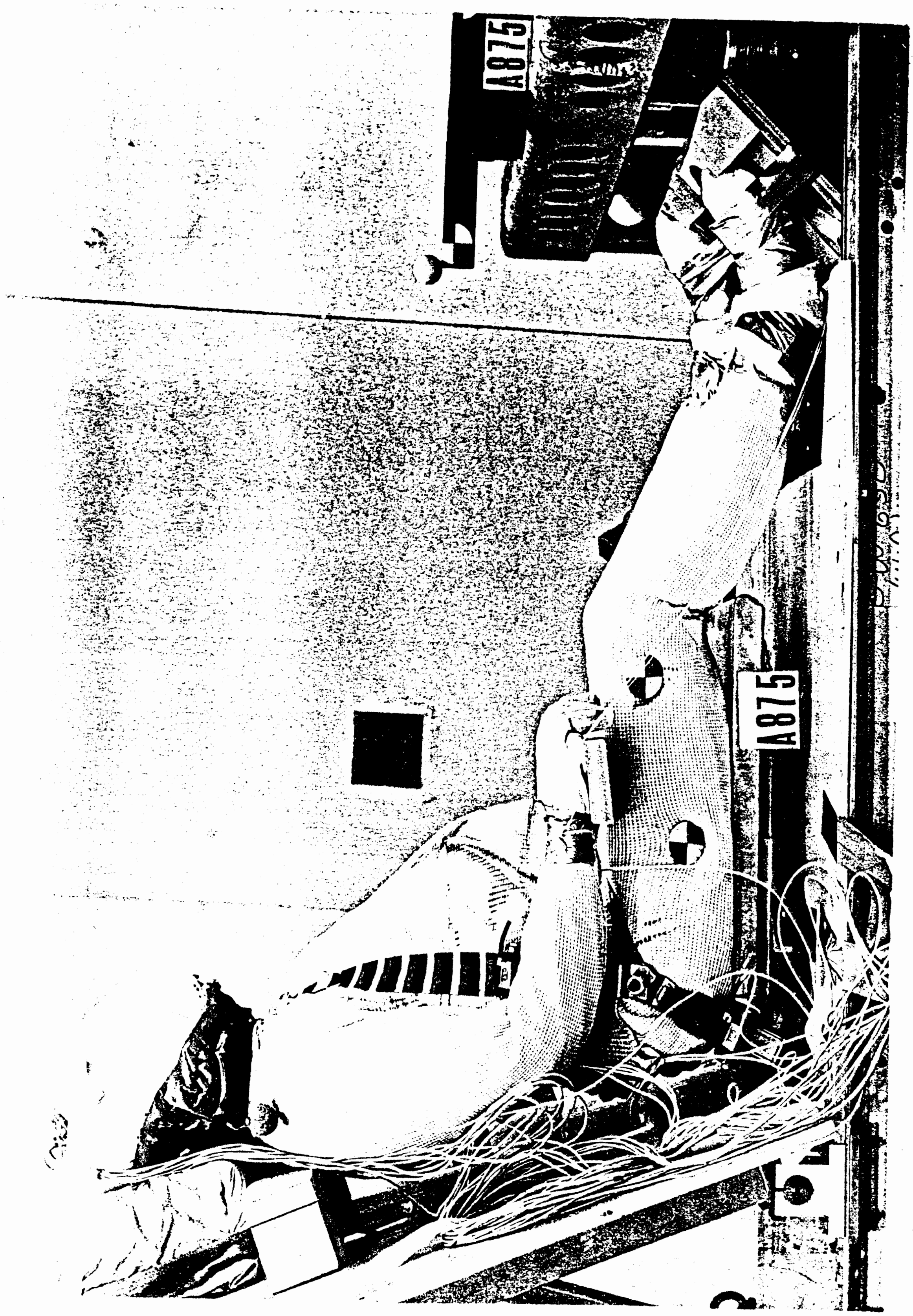
SETUP PHOTOGRAPH: TEST A-874



GRAPHCHECK PHOTOGRAPH: TEST A-874

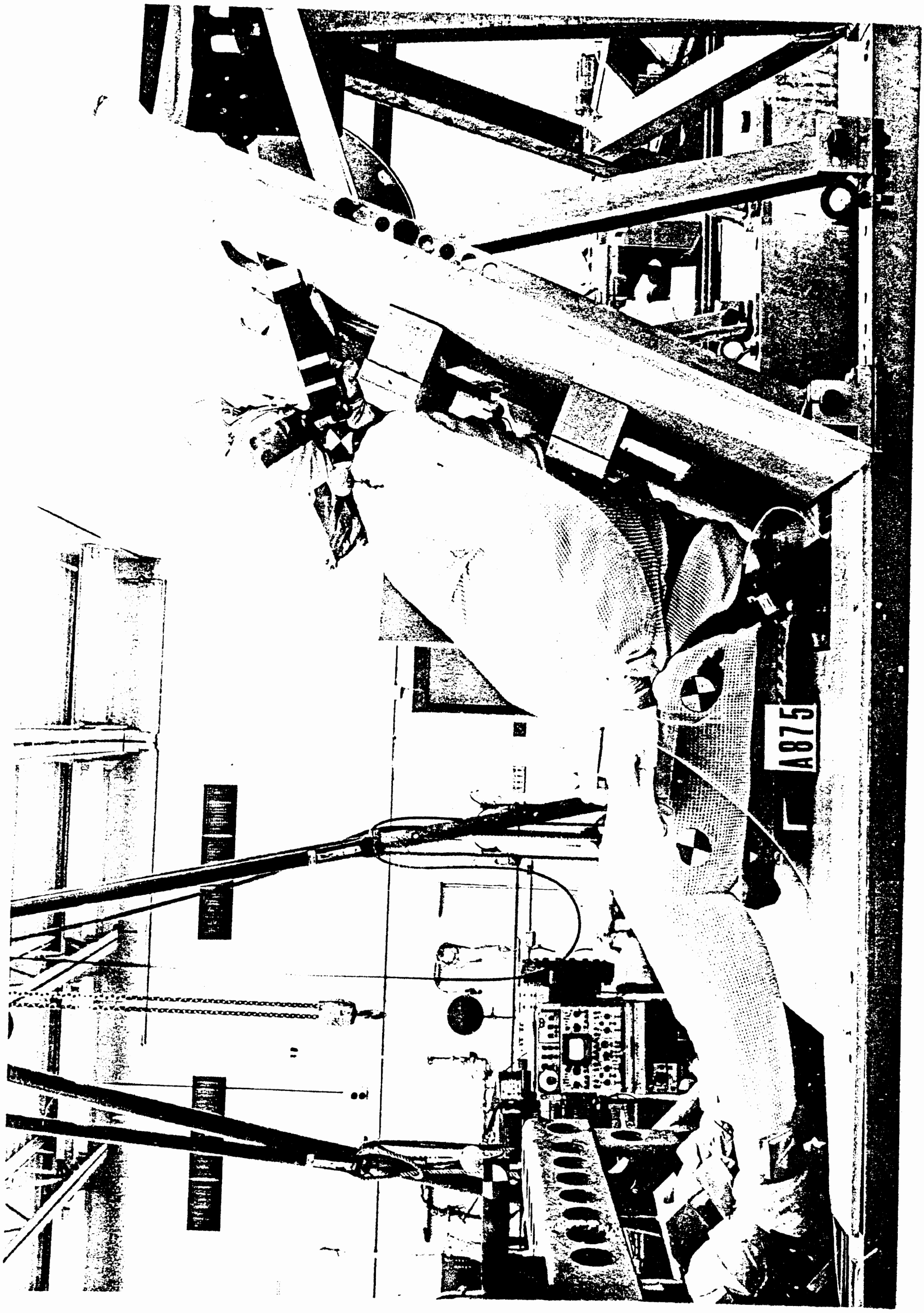


TEST PHOTOGRAPH: WBR-5 TEST A-874

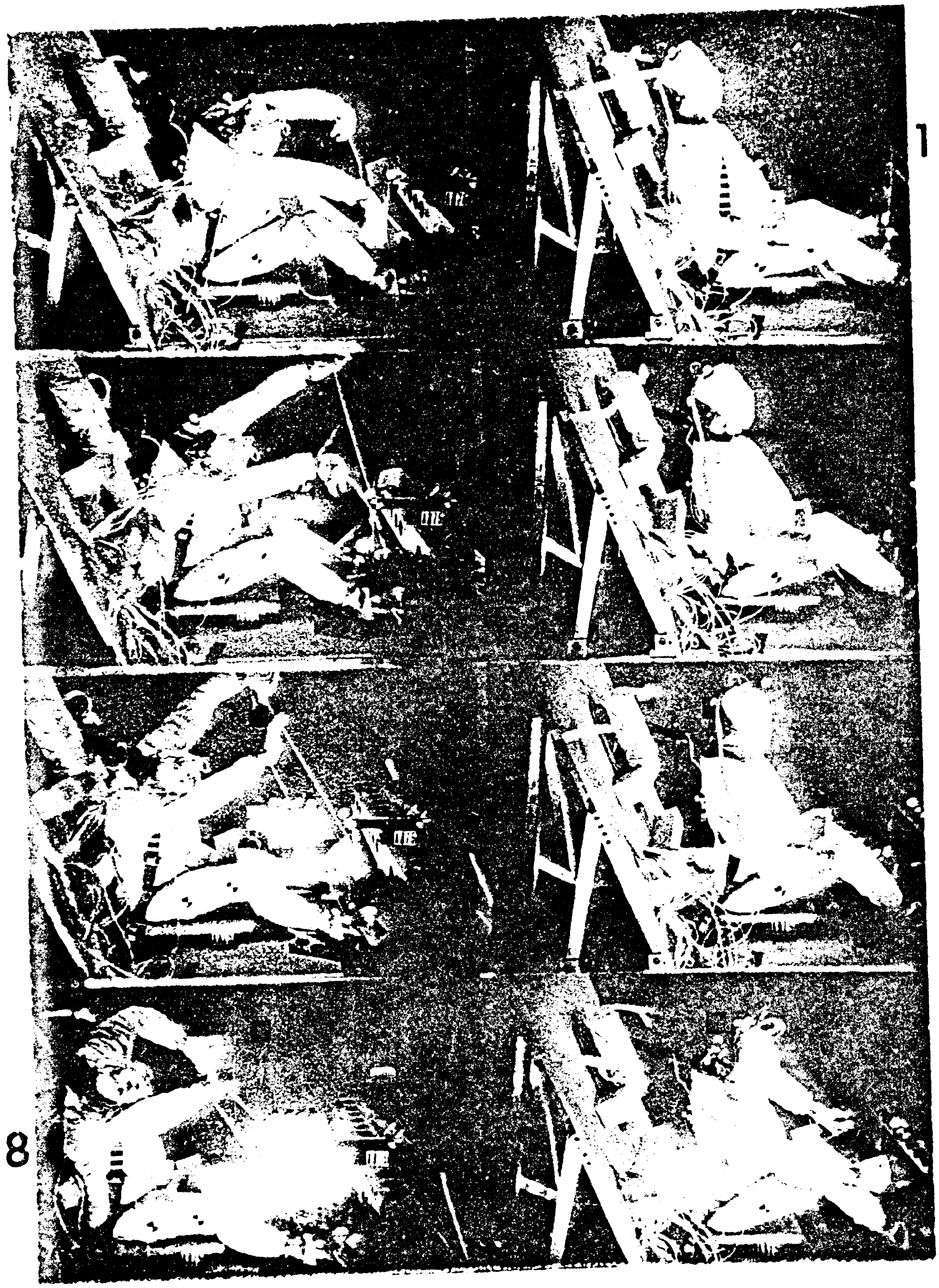


SETUP PHOTOGRAPH: TEST A-875

SETUP PHOTOGRAPH: TEST A-875

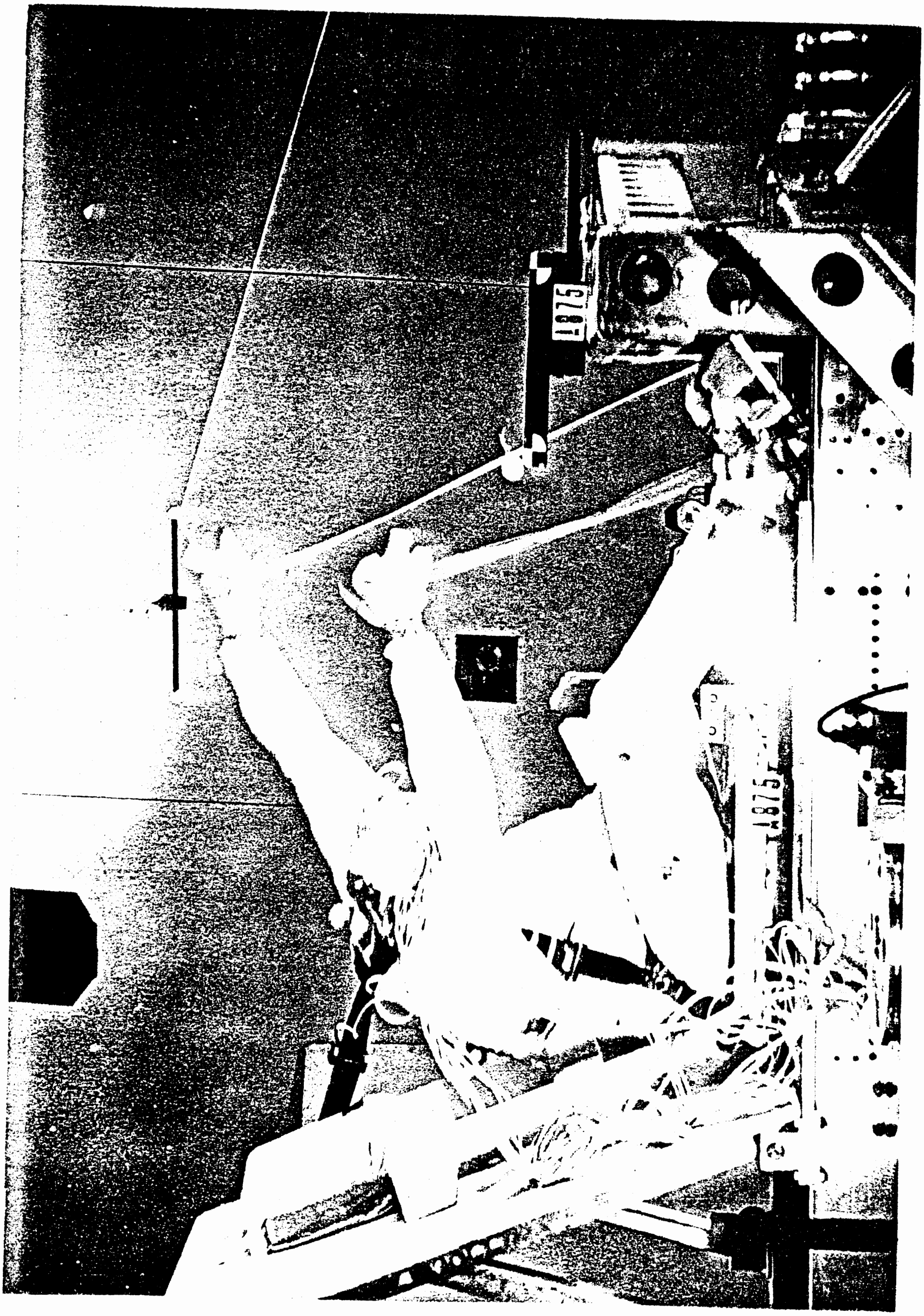


SETUP PHOTOGRAPH: TEST A-875

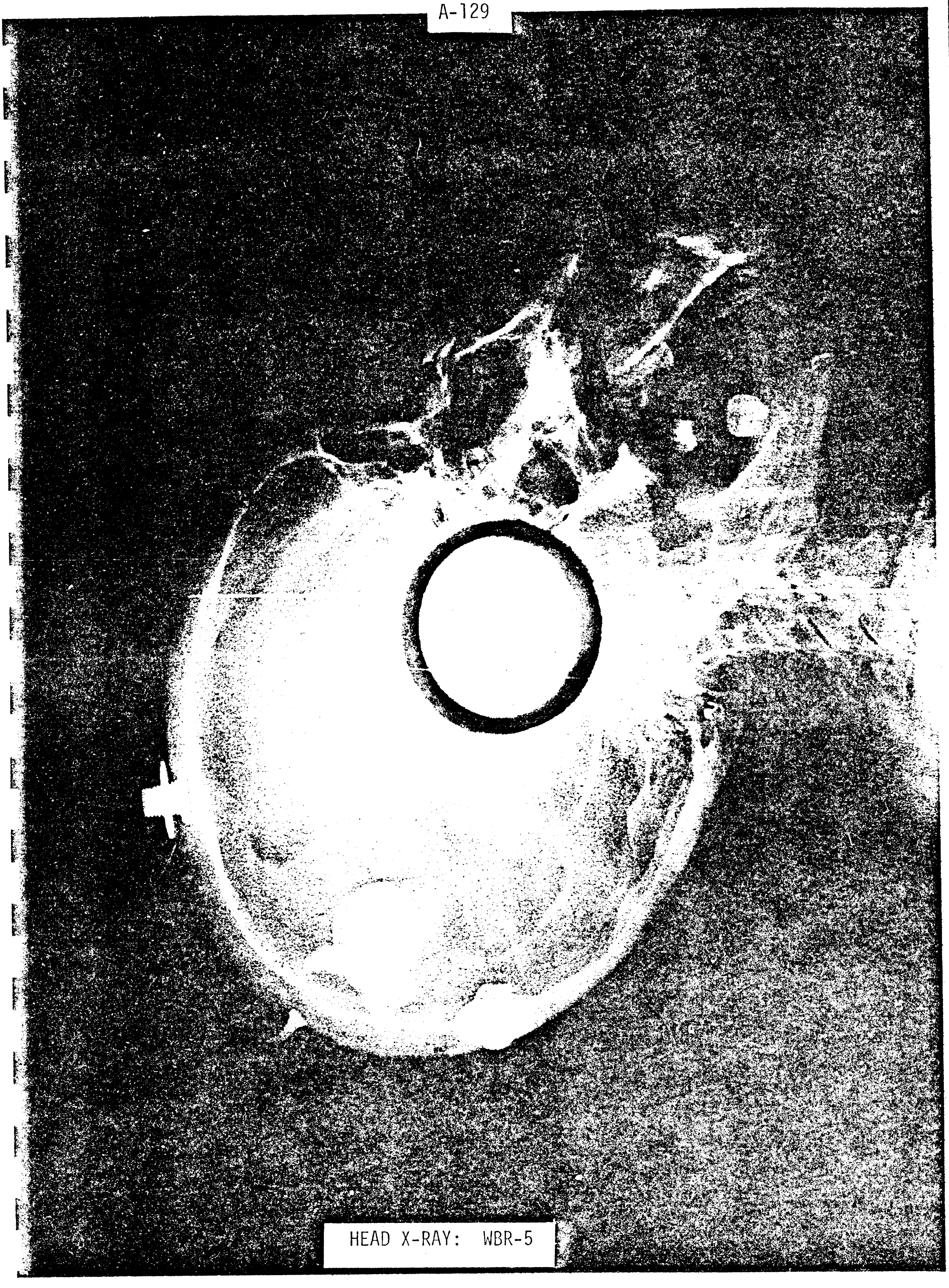


A875

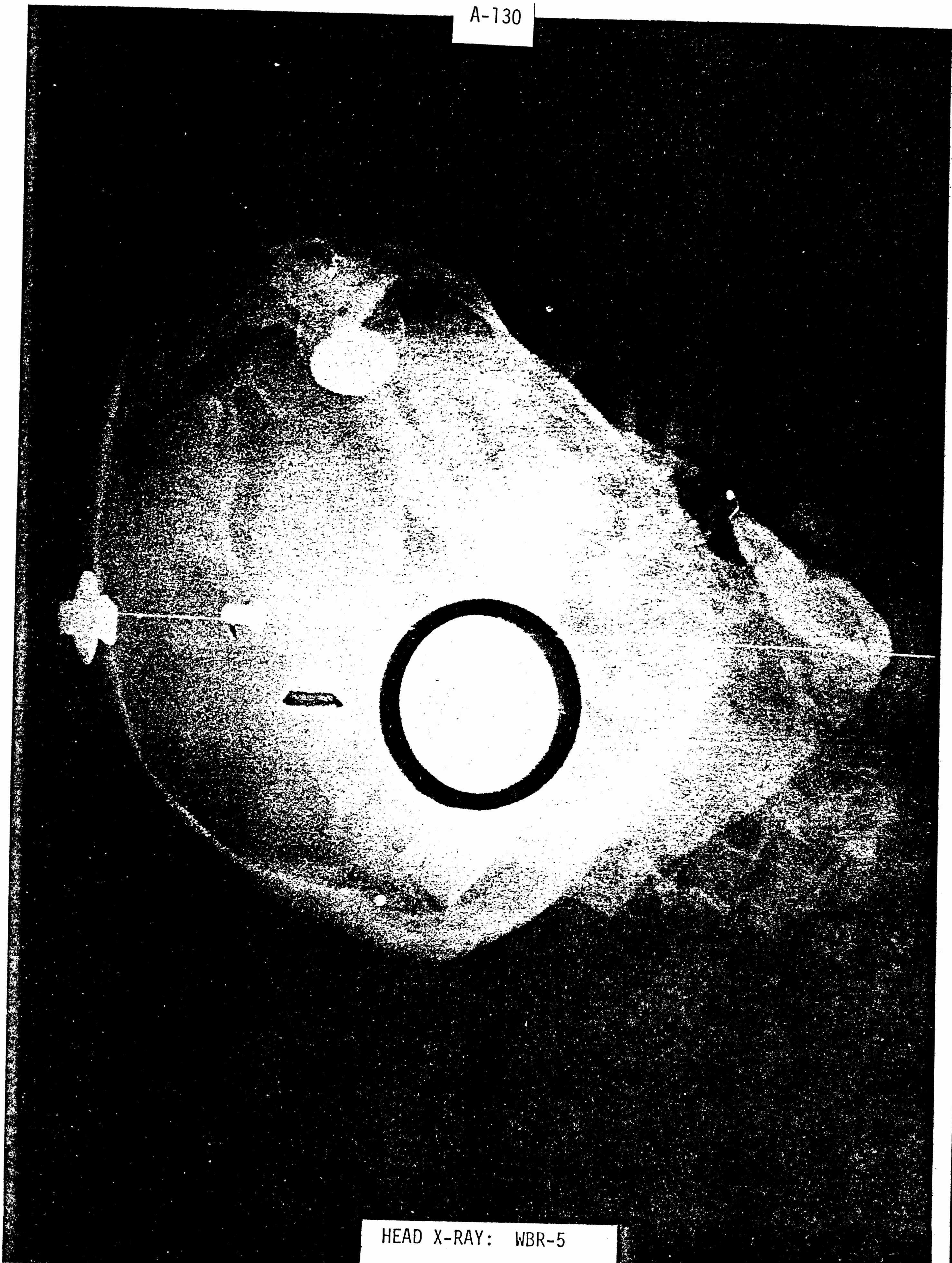
GRAPHCHECK PHOTOGRAPH: TEST A-875



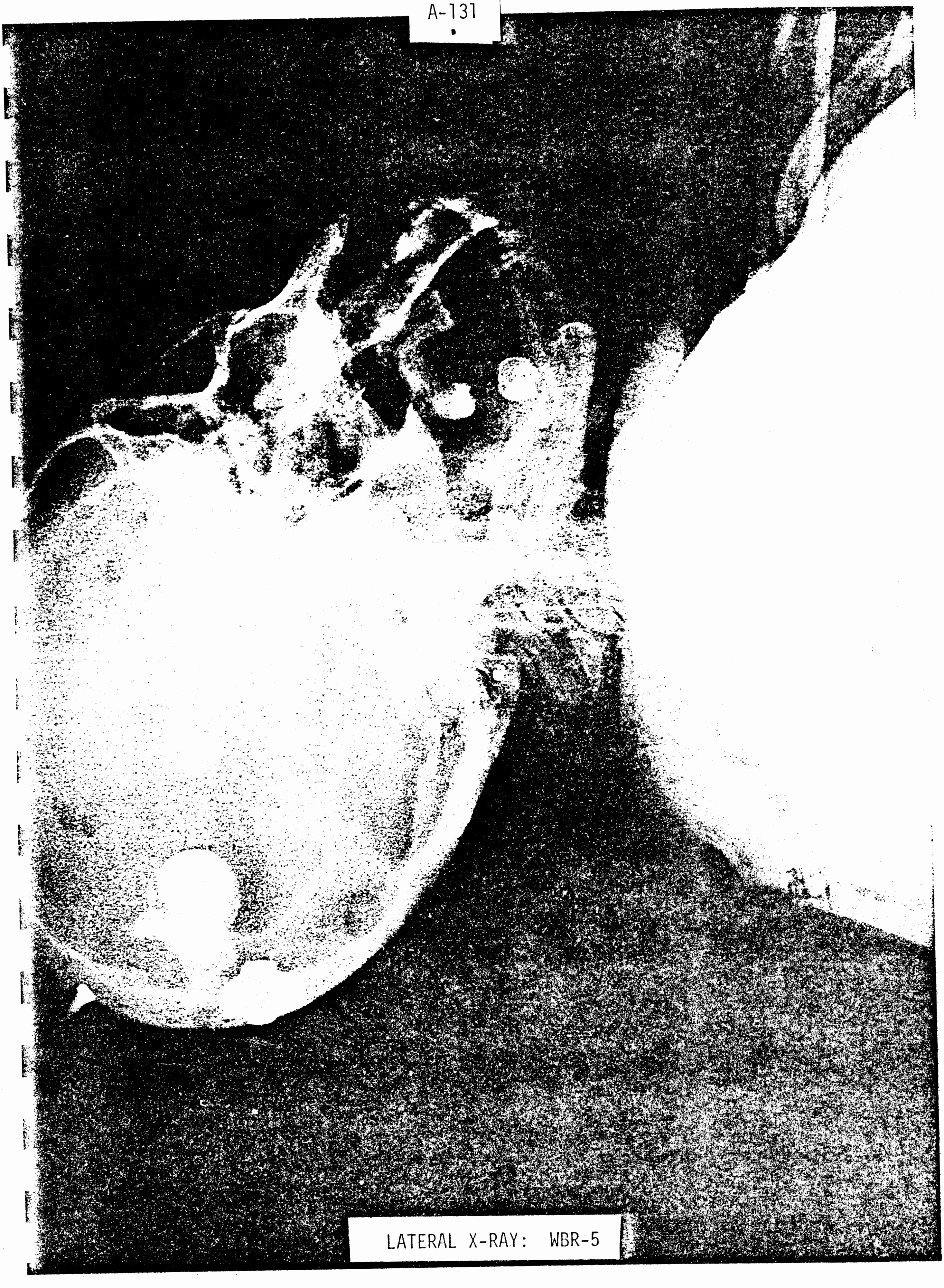
TEST PHOTOGRAPH: WBR-5 TEST A-875



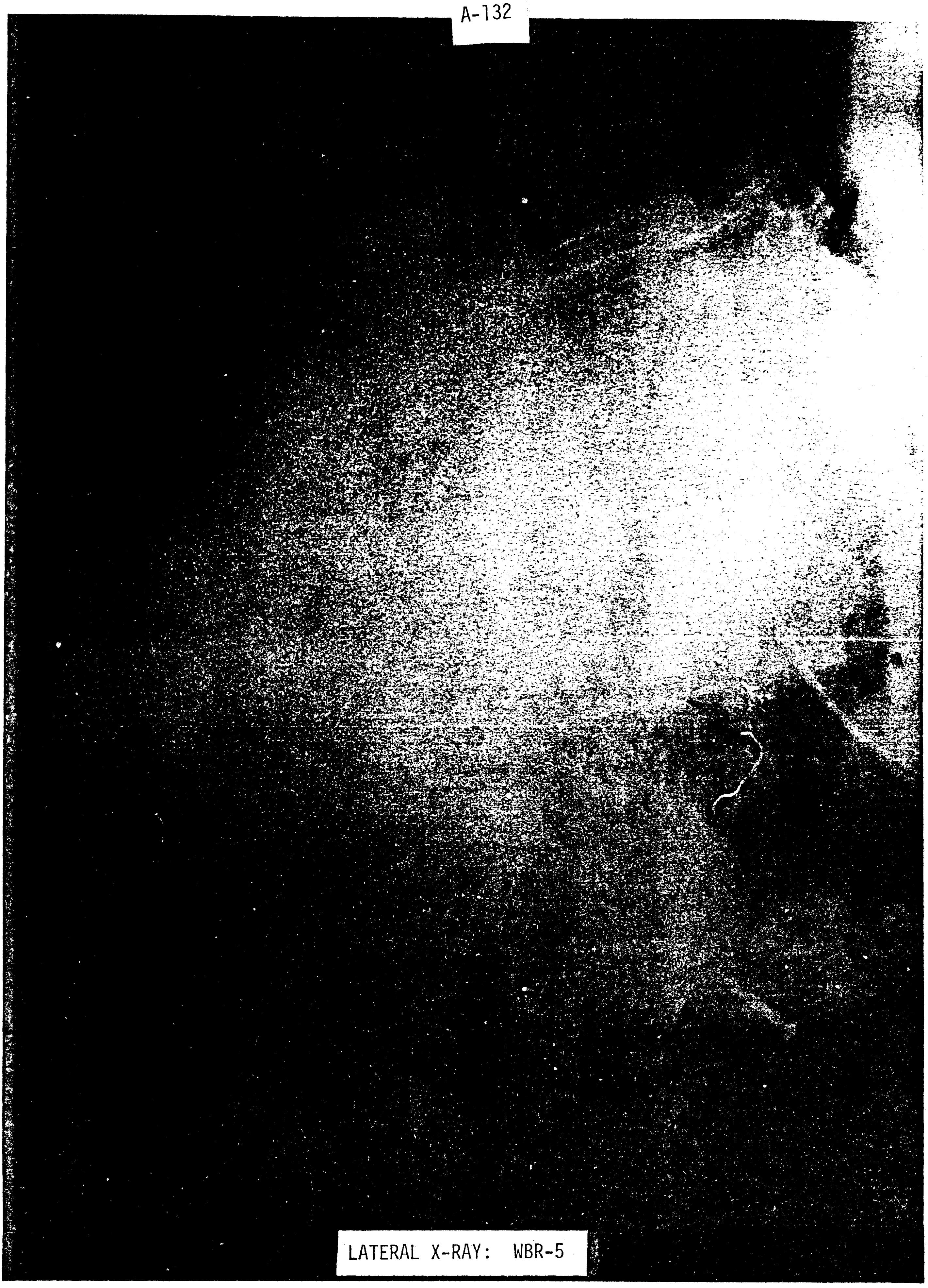
HEAD X-RAY: WBR-5



HEAD X-RAY: WBR-5

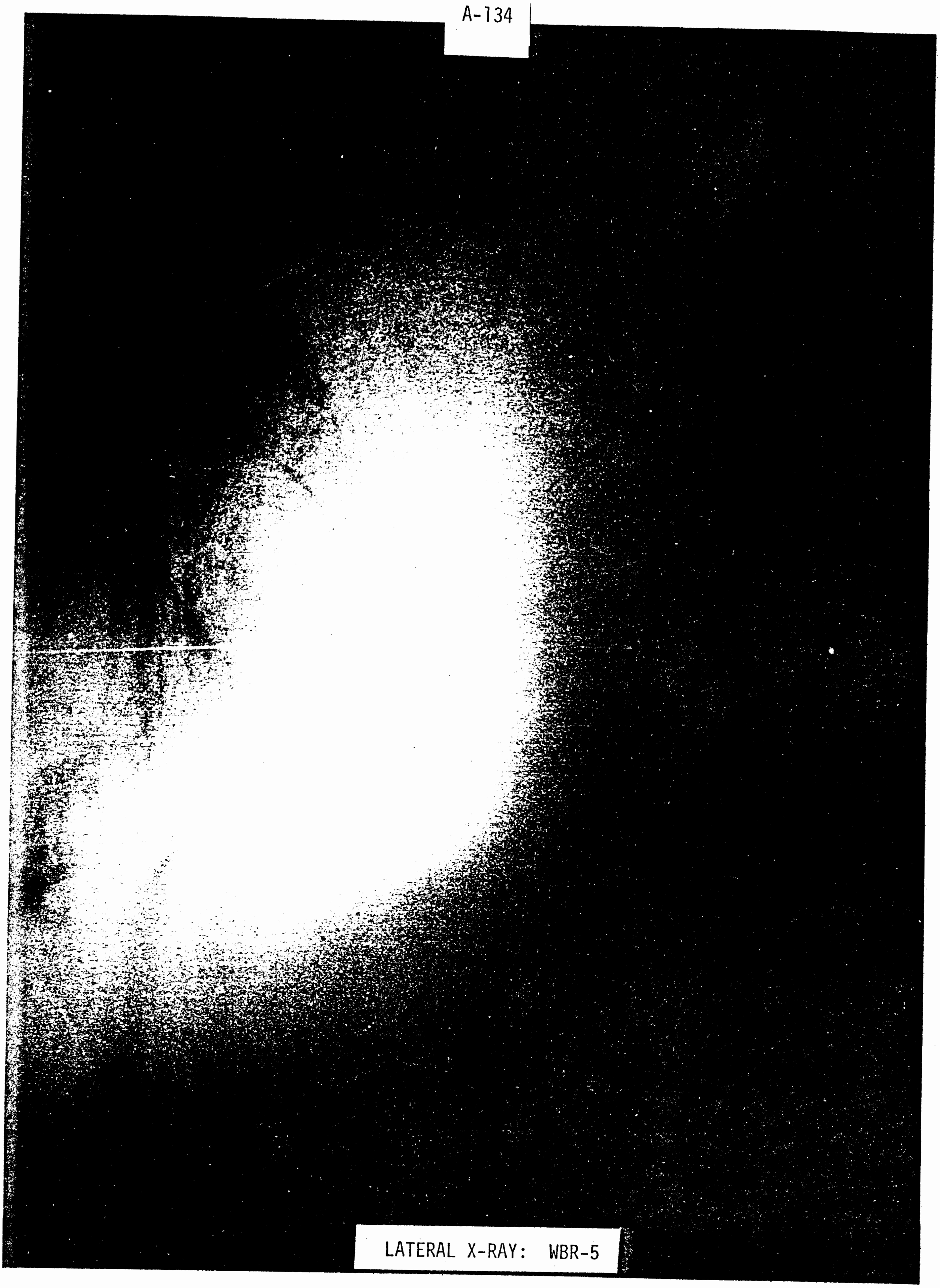


LATERAL X-RAY: WBR-5

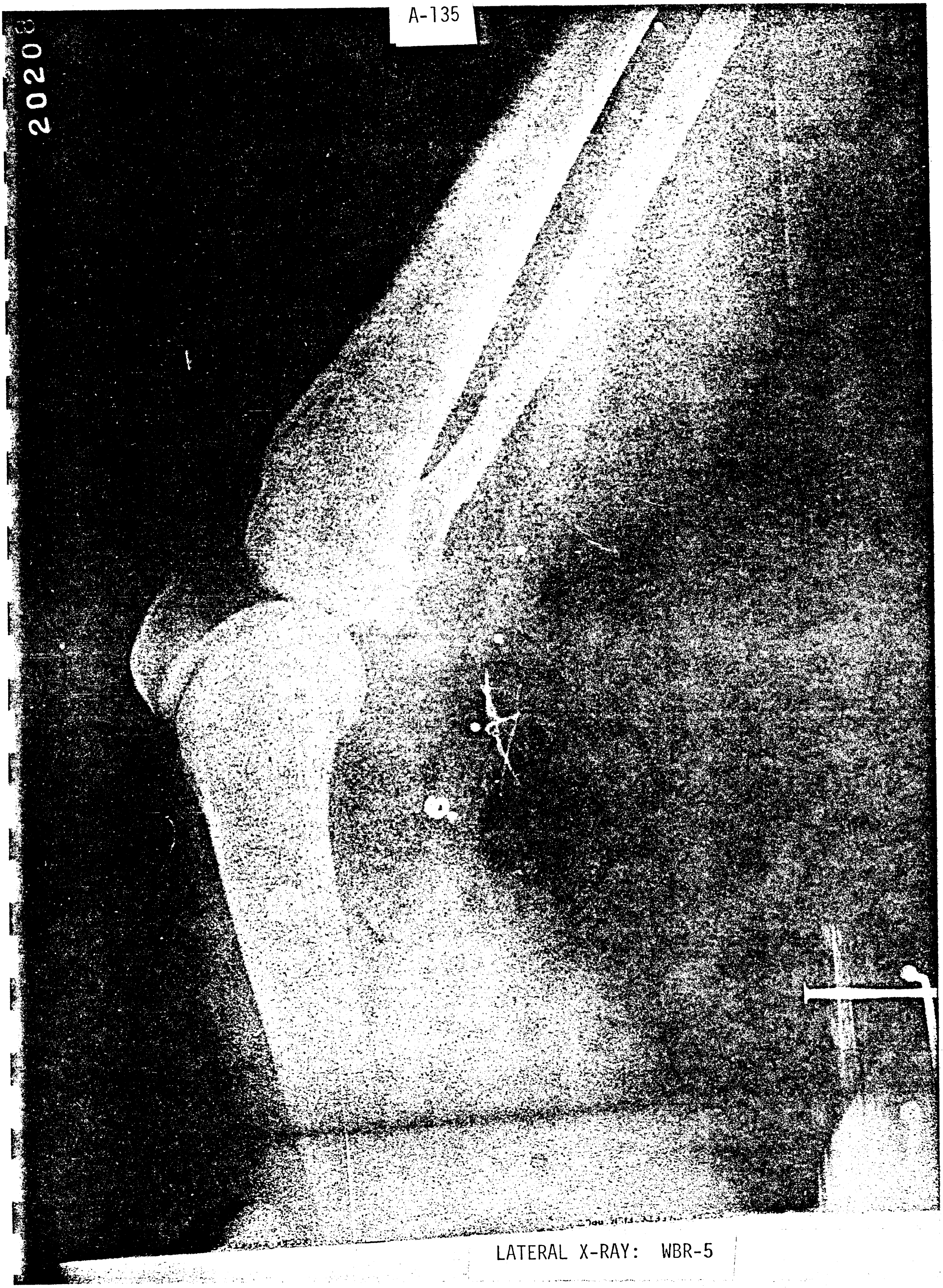


LATERAL X-RAY: WBR-5

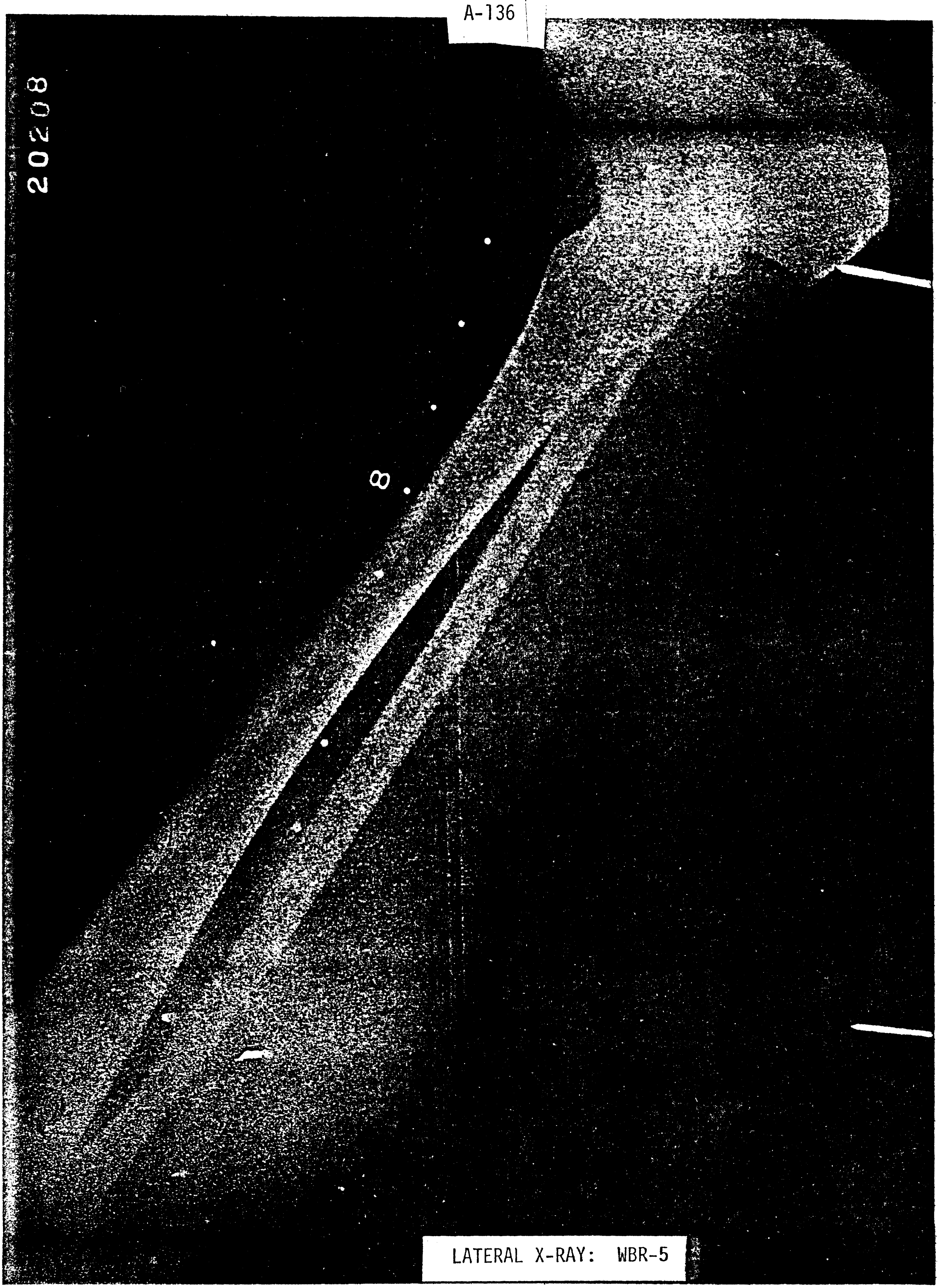
LATERAL X-RAY: WBR-5



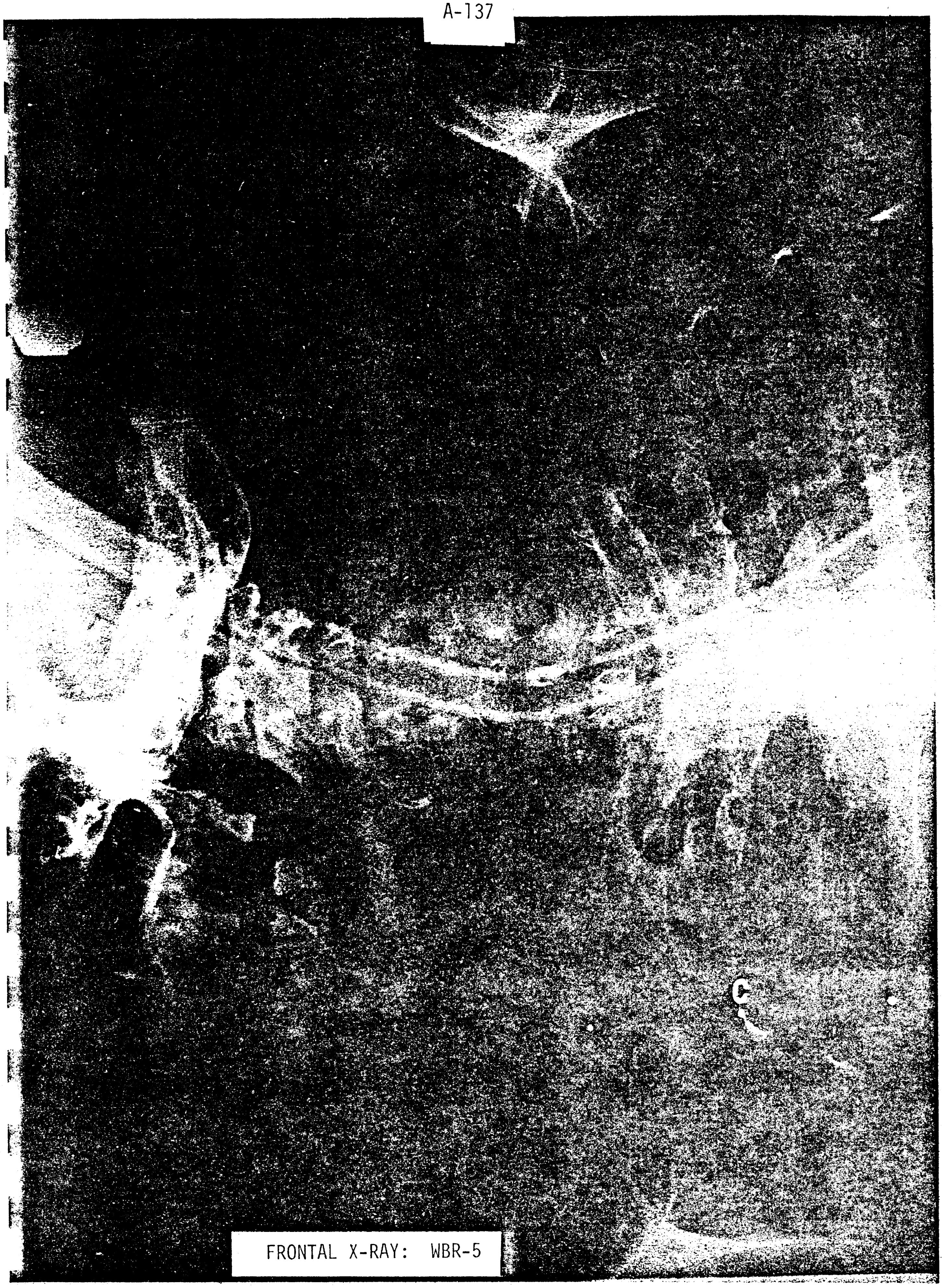
LATERAL X-RAY: WBR-5



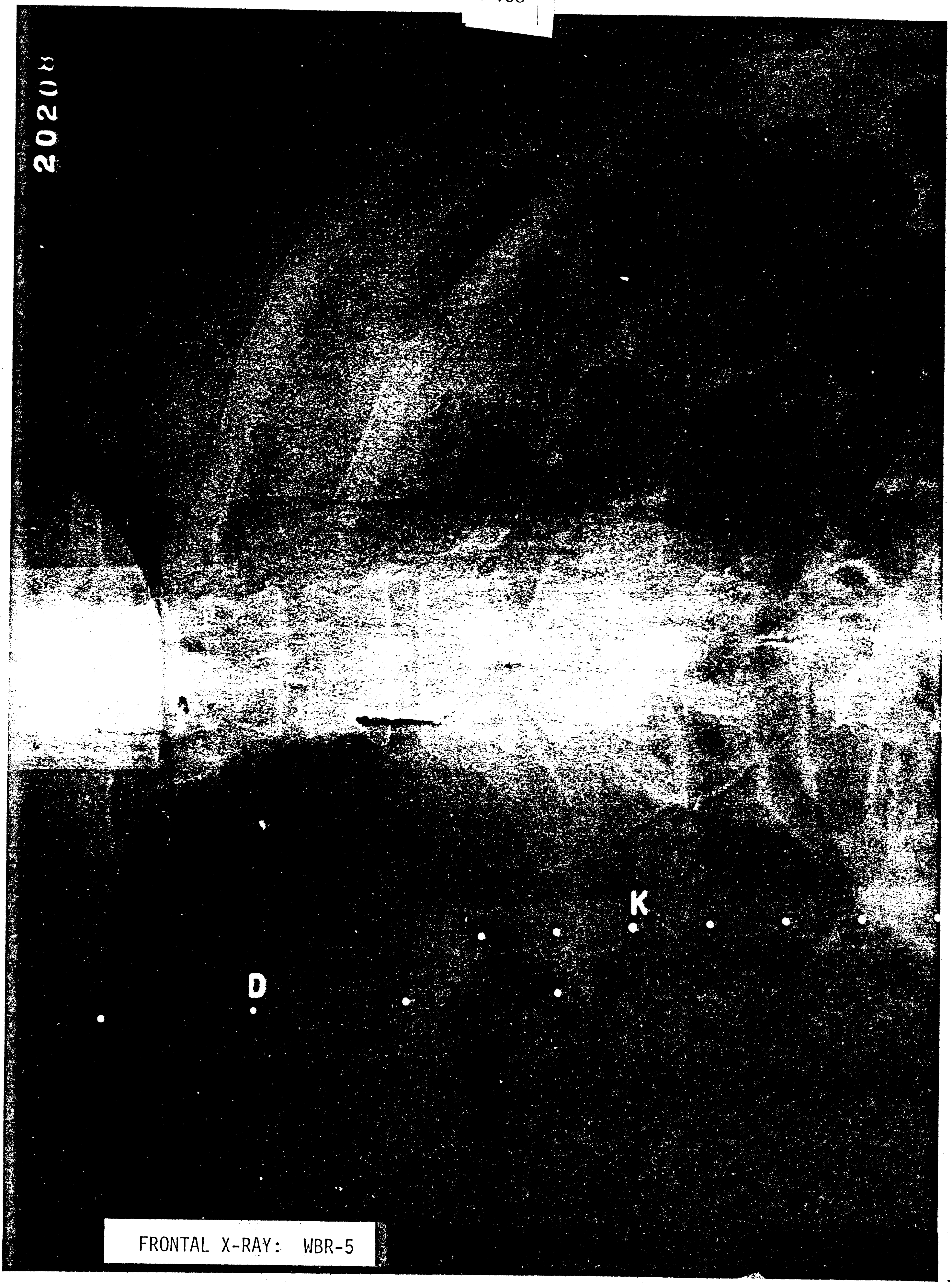
LATERAL X-RAY: WBR-5



LATERAL X-RAY: WBR-5



FRONTAL X-RAY: WBR-5

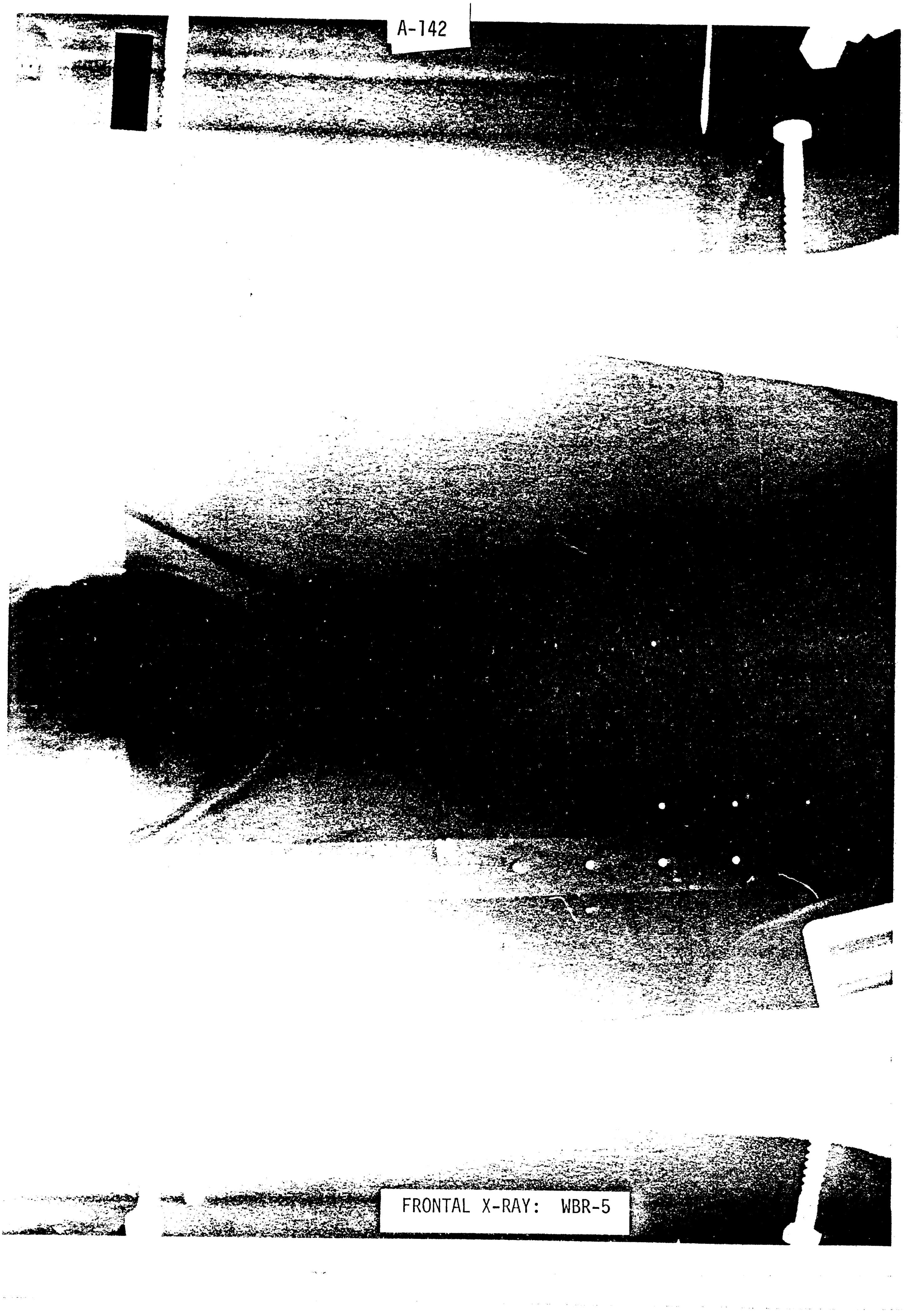


FRONTAL X-RAY: WBR-5

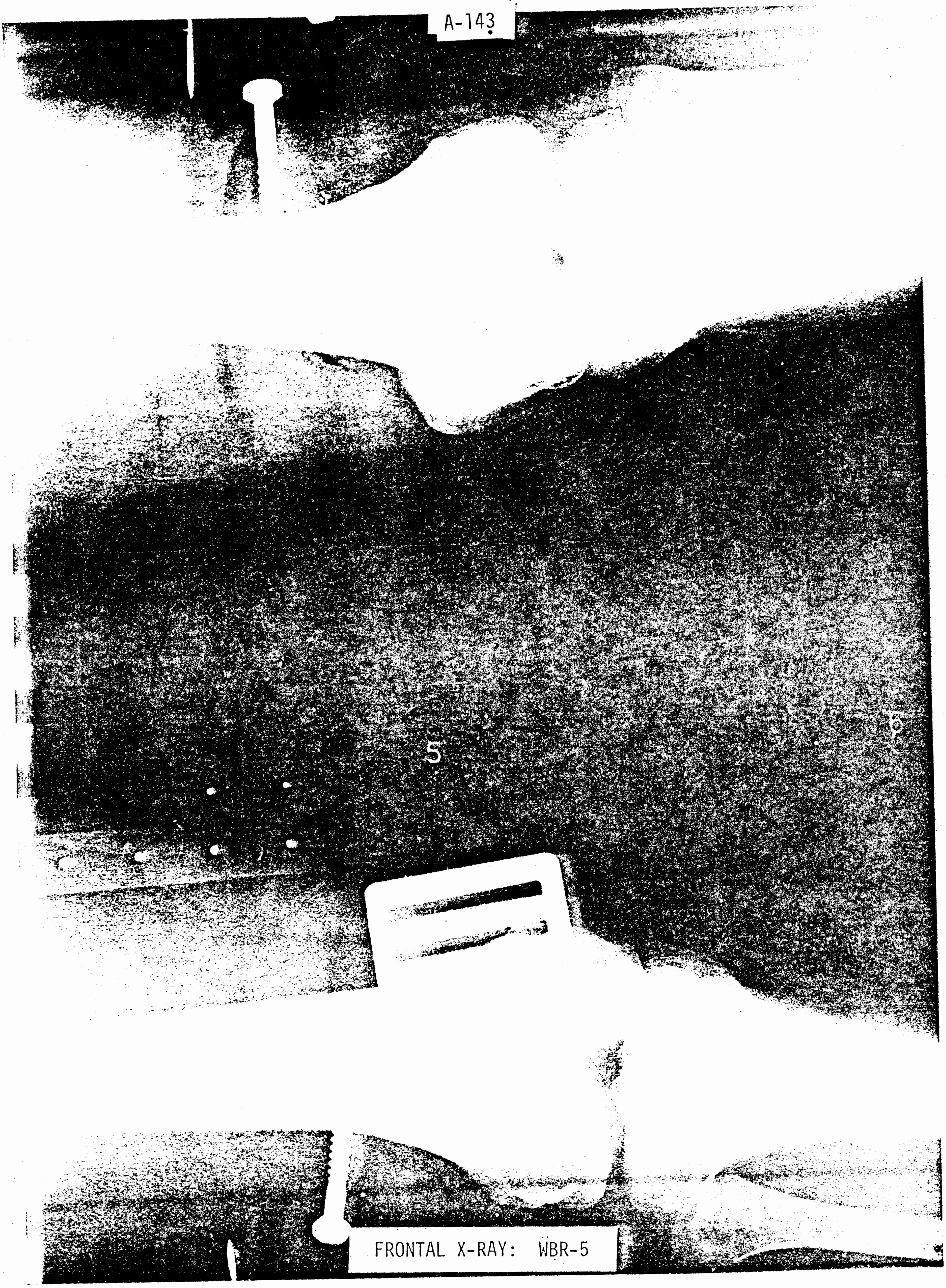
FRONTAL X-RAY: WBR-5

FRONTAL X-RAY: WBR-5

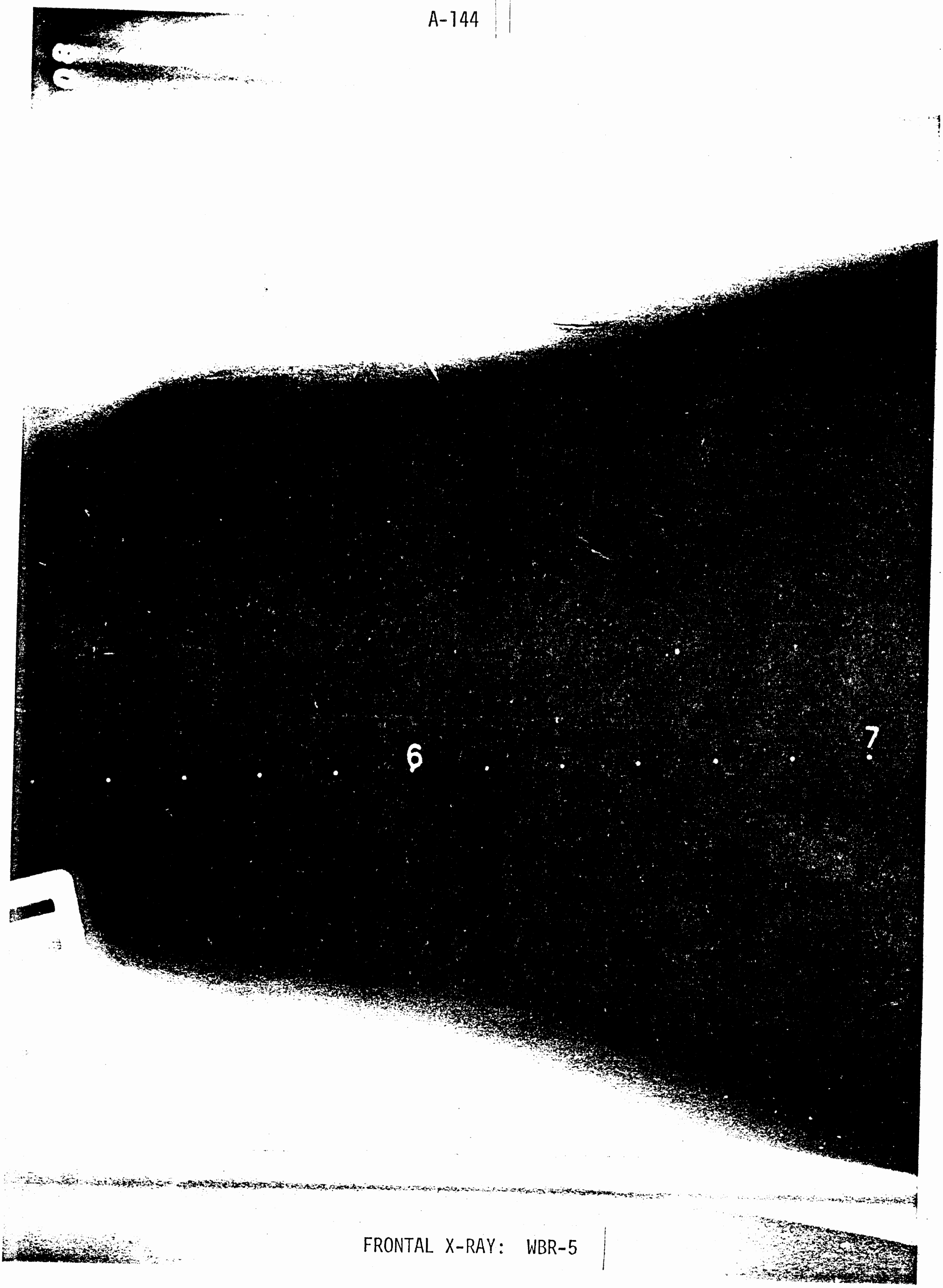
FRONTAL X-RAY: WBR-5



FRONTAL X-RAY: WBR-5



FRONTAL X-RAY: WBR-5



FRONTAL X-RAY: WBR-5

WHOLE BODY RESPONSE

TEST SUMMARY

TEST SERIES WBR-6

TESTS A-881 AND A-882

WHOLE BODY RESPONSE

SLED TEST SUMMARY

WBR# 6 DATE 7-1-75

SLED TEST NOS. A- 881 AND A- 882

TEST SUBJECT DATA

CADAVER ID NO.: 20218 LUNGS PRESSURIZED: Yes

AGE: 60 years WEIGHT: 125 lbs.

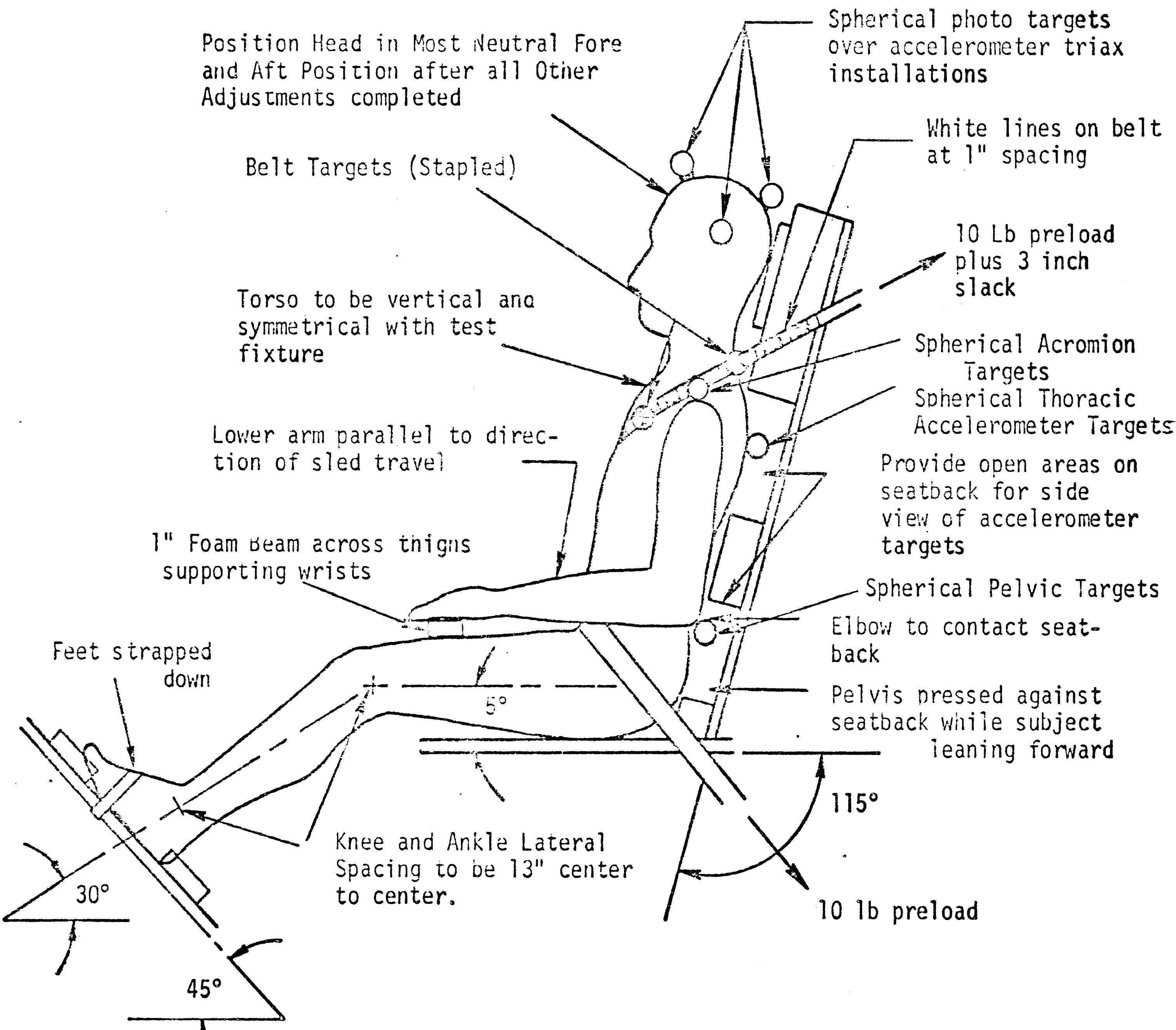
HEIGHT 169.7 SEX: M

TEST PARAMETERS

	FIRST IMPACT	SECOND IMPACT
VELOCITY:	17.8 MPH	24.2 MPH
DECELERATION:	10.0 G's	9.7 G's
IMPACT DIRECTION:	FRONTAL	FRONTAL
RESTRAINT SYSTEM:	3 pt. belt	3 pt. belt

POST IMPACT EVALUATION

	FIRST IMPACT	SECOND IMPACT
a. Test Subject:		
Any Injury	---	---
Submarining	None	None
b. Restraint System	---	---
Damage:	None	None
c. Transducers:		
Any Units Damaged	None	None
Any Units Loosened	Trach Tube Disconnected during Impact.	
d. Any Data Lost:		



Initial Belt Lengths: R. Lap = 12"
(Center to Center of Ends) L. Lap = 32.5"
Shoulder = 42"

Femur Target Spacing:

Right Side = ---- in.

Left Side = ---- in.

POSITIONING AND TARGETING DIAGRAM WBR-6

WHOLE BODY RESPONSE WBR# 6

BELT LENGTH DATA

TEST A- 881

Belt Position	Pre-Impact Length (in)	Post-Impact Length (in)	Belt Stretch (in)	Post-Impact Length with Load Cells
Rt. Lap	12	12	0	11 1/2
Lt. Lap	32 1/2	32 1/4	- 1/4	31 1/2
Shoulder	42	42	0	40 1/2

Test A- 882

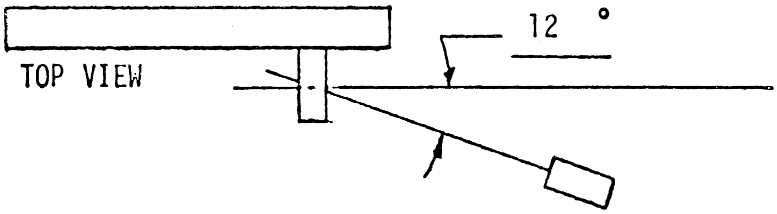
Belt Position	Pre-Impact Length (in)	Post-Impact Length (in)	Belt Stretch (in)	Post-Impact Length with Load Cells
Rt. Lap	12	11 3/4	- 1/4	11 1/8
Lt. Lap	32 1/2	32 1/2	0	31 7/8
Shoulder	42	40 3/4	- 1 1/4	40 1/8

WBR# 6

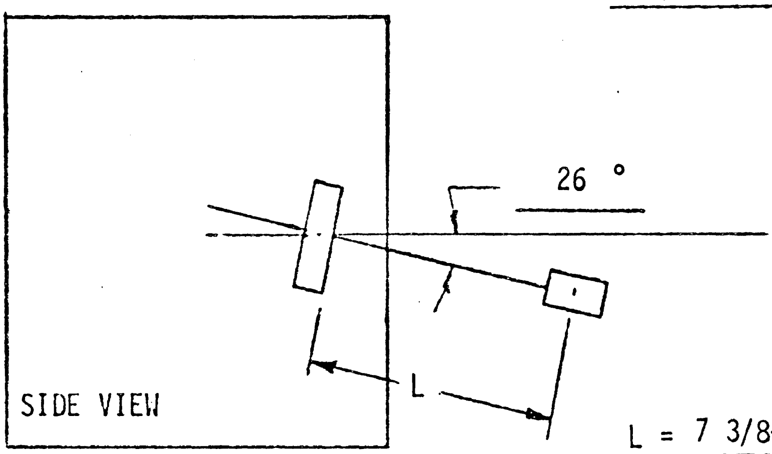
Test No. A-881

WHOLE BODY RESPONSE

BELT ANCHOR ORIENTATIONS

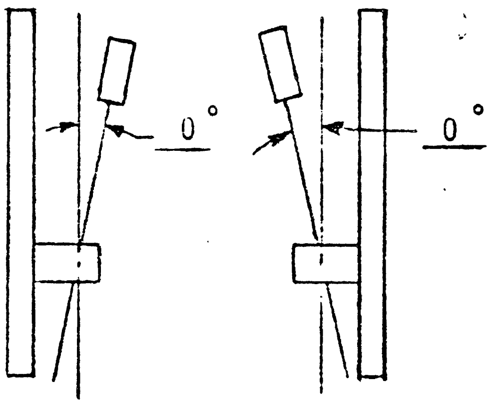


SHOULDER BELT



L = 7 3/8 in.

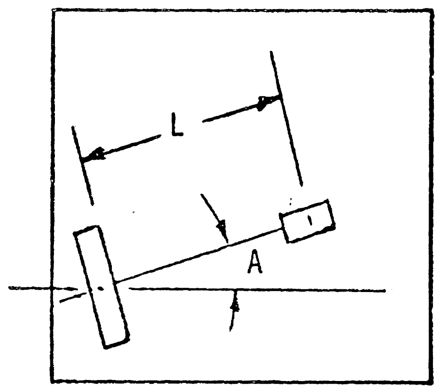
LAP BELT



LEFT SIDE

RIGHT SIDE

TOP VIEW



SIDE VIEW

L_{LEFT} = 2 5/32 in.

L_{RIGHT} = 3 in.

A_{LEFT} = 45 °

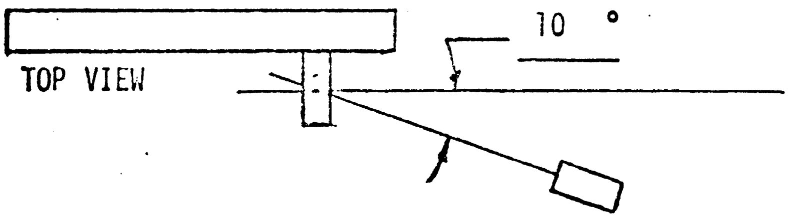
A_{RIGHT} = 40 °

WBR# 6

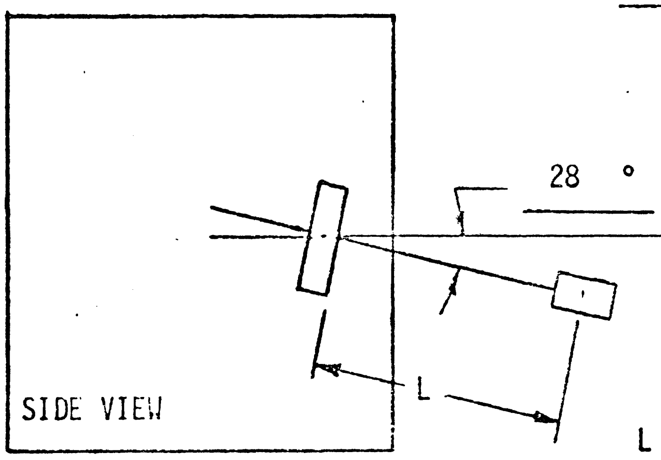
Test No. A-882

WHOLE BODY RESPONSE

BELT ANCHOR ORIENTATIONS

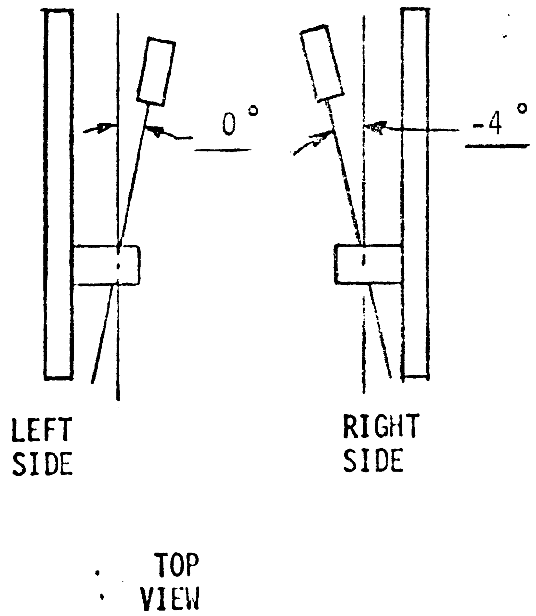


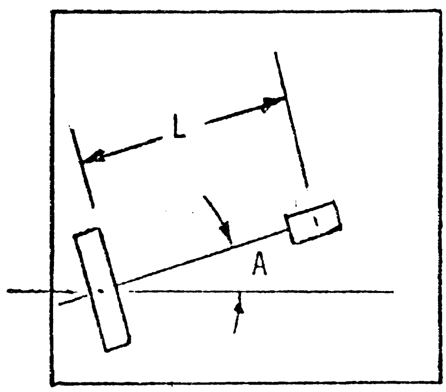
SHOULDER BELT



L = 7 1/4in.

LAP BELT





SIDE VIEW

L_{LEFT} = 2 1/4 in.

L_{RIGHT} = 3 1/4 in.

A_{LEFT} = 48 °

A_{RIGHT} = 52 °

INSTRUMENTATION DATA SHEET

TEST NO. WBR-6 SLED RUN NO. A-881; A-882 DATE 7-1-75 PREPARED BY

TAPE DATA: RECORDER Honeywell RECORD SPEED 30 IPS

	TAPE			TRANSDUCER			CALIBRATION						
CHAN.	INPUT	40% (3V) MODULATION VALUE	RUN GAIN	EXCIT. VOLT.	TYPE	S/N	CAL. RESISTOR	CAL. VOLTAGE	CAL. GAIN	CAL. VALUE	+ -	OUTPUT RUN SENSITIVITY	CHAN.
1	Sled Decel		200		Stath	13587				22G/ 44G	+	20 G/V	1
2	Head Q- 1A	-124.65G	100	10	Endev	AB56	199.3K	-1.16	100	48.2G	-	41.55 G/V	2
3	Head Q- 1B	-144.78G	100	10	"	AB59	200.0K	-1.16	100	56.4G	-	48.62 G/V	3
4	Head Q- 1C	-124.35G	100	10	"	AB60	199.6K	-1.17	100	48.5G	-	41.45 G/V	4
5	Head Q- 2C	-170.16G	100	10	"	AB61	199.4K	-1.16	100	65.8G	-	56.72 G/V	5
6	Head Q- 2A	-135.78G	100	10	"	AB79	199.4K	-1.16	100	52.5G	-	45.26 G/V	6
7	Head Q- 2B	-141.72G	100	10	"	AB85	199.5K	-1.16	100	54.8G	-	47.24 G/V	7
8	Head Q- 3B	-118.98G	100	10	"	AB87	199.5K	-1.17	100	46.4G	-	39.66 G/V	8
9	Head Q- 3C	-128.52G	100	10	"	AB90	199.6K	-1.16	100	49.7G	-	42.84 G/V	9
10	Head Q- 3A	-132.93G	100	10	"	AB97	199.4K	-1.16	100	51.4G	-	44.31 G/V	10
11													11
12	Velocity Pulse		10									12"/Pulse	12
13	Dig. Gate												13
14	Time Base											.01 sec/ pulse	14

INSTRUMENTATION DATA SHEET

TEST NO. WBR-6 SLED RUN NO. A-881; A-882 DATE 7-1-75 PREPARED BY

TAPE DATA: RECORDER CEC RECORD SPEED 30 IPS

TAPE				TRANSDUCER			CALIBRATION						
CHAN.	INPUT	40% (3V) MODULATION VALUE	RUN GAIN	EXCIT. VOLT.	TYPE	S/N	CAL. RESISTOR	CAL. VOLTAGE	CAL. GAIN	CAL. VALUE	±	OUTPUT RUN SENSITIVITY	CHAN.
1	Sled Decel.		200		Stath	13587				22G/ 44G	+	20 G/V	1
2	Pelvis P-A	-149.25 G	100	10	Endev	AC04	199.4K	- 1.18	100	58.7G		49.75 G/V	2
3	Pelvis I-S	-147.72 G	100	10	"	AC06	199.5K	- 1.18	100	58.1G		49.24 G/V	3
4	Thorax P-A	-133.44 G	100	10	"	AC14	199.4K	- 1.16	100	51.6G		44.48 G/V	4
5	Thorax I-S	160.2 G	100	10	"	AA49	199.2K	+ 1.25	100	66.8G		53.4 G/V	5
6	Thorax R-L	133.8 G	100	10	"	AA58	199.2K	+ 1.26	100	56.2G		44.6 G/V	6
7	Rt. Lap	3145.74#	200	-	G.S.E	082	50 K	2.20	200	2209#	+	1004.1 #/V	7
8	Lt. Lap	3016.2 #	200	-	"	083	50 K	2.23	200	2242#	+	1005.4 #/V	8
9	Up. Shldr.	3009.3 #	VAR	-	"	084	50 K	+ 2.27	-	2277#	+	1003.1 #/V	9
10	Low Shldr.	2476.2 #	VAR	-	"	085	50 K	2.72	-	2245#	+	825.4 #/V	10
11													11
12	Velocity		10										12
13	Dig. Gate												13
14	Time Base												14

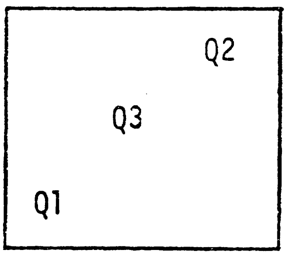
HEAD X-RAY DATA SHEET

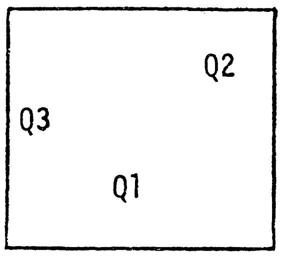
WHOLE BODY RESPONSE PROJECT

WBR NO. 6

TARGET		INSTALLATION FIXTURE DIMENSION	DISTANCE FROM X-RAY PLANE X-Z PLANE (Side view)	Y-Z PLANE (Frontal)
ACCELEROMETERS				
Location	Name			
Collet Furthest to Right-Rear of Head	Q_1	3.838	8.5	15.25
Next Collet clockwise from Q_1 (viewed from top)	Q_2	3.155	6.25	15.5
Next Collet clockwise from Q_2 (viewed from top)	Q_3	4.025	12.25	15.0
ANATOMICAL MARKER PELLETS				
Right Eye		□	10.0	21.5
Left Eye		□	7.0	21.0
Right Ear		○	11.0	20.0
Left Ear		○	5.5	17.0
X-RAY DATA				
VOLTAGE				
CURRENT				
TIME				
SATISFACTORY? (Check if Yes)				

Sketch of Relative Positions of Accelerometer Targets As Viewed from X-Ray Source.





WHOLE BODY RESPONSE: ANTHROPOMETRY

CADAVER ID: 20218

DATE: 6-24-75

ANTHROPOMETRIST: H. M. Reynolds

Anthropometric Measurements:

(A = Anthropometer; Sp. C. = Spreading Calipers; Sl. C. = sliding calipers; T = Tapes)

1.	Weight		117.8
2.	Stature (A)		169.8
3.	Trochanterion Hgt. (A)	Rt.	85.5
		Lt.	86.7
4.	Anterior-Superior Iliac Spine Hgt. (A)	Rt.	78.4
		Lt.	79.2
5.	Iliocristale Hgt. (A)	Rt.	71.3
		Lt.	71.7
6.	Substernale Hgt. (A)		50.1
7.	Axilla Hgt. (A)		
8.	Suprasternale Hgt. (A)		31.3
9.	Nipple Hgt. (A)		41.8
10.	Mastoid Hgt. (A)		15.3
11.	Nuchale Hgt. (A)		14.2
12.	Tragion Hgt. (A)	Rt.	12.6
		Lt.	12.9
13.	Menton Hgt. (A)		21.7
14.	Head Breadth (Sp. C.)		17.0
15.	Head Length (Sp. C.)		18.3

Cad. I.D. 20218

16.	Bitragion Diameter (Sp. C.)	15.3
17.	Bigonial Diameter (Sp. C.)	11.1
18.	Menton Diagonal (Sp. C.)	23.9
19.	Mastoid Diagonal (A)	15.1
20.	Head Circumference (T)	55.6
21.	Mid-Sagittal Arc Length (T)	31.8
22.	Coronal Arc Length (T)	36.3
23.	Mid-Neck Circumference (T)	
24.	Chest Circumference at Axilla (T)	78.0
25.	Chest Circumference at Nipple (T)	81.9
26.	Chest Circumference at Substernale (T)	88.7
27.	Hip Circumference, Iliocristale (T)	81.5
28.	Buttocks Circumference, Trochanterion (T)	78.8
29.	Upper Arm Circumference, Axilla (T)	21.9
30.	Upper Arm Circumference, Mid Biceps (T)	15.3
31.	Upper Arm Circumference, Humeral Condyles (T)	19.9
32.	Maximum Forearm Circumference (T)	20.6
33.	Wrist Circumference (T)	15.5
34.	Upper Thigh Circumference (T)	37.5
35.	Mid-Thigh Circumference (T)	31.3
36.	Lower Thigh Circumference (T)	27.9
37.	Maximum Calf Circumference (T)	26.8
38.	Ankle Circumference (T)	21.9

Cad. I.D. 20218

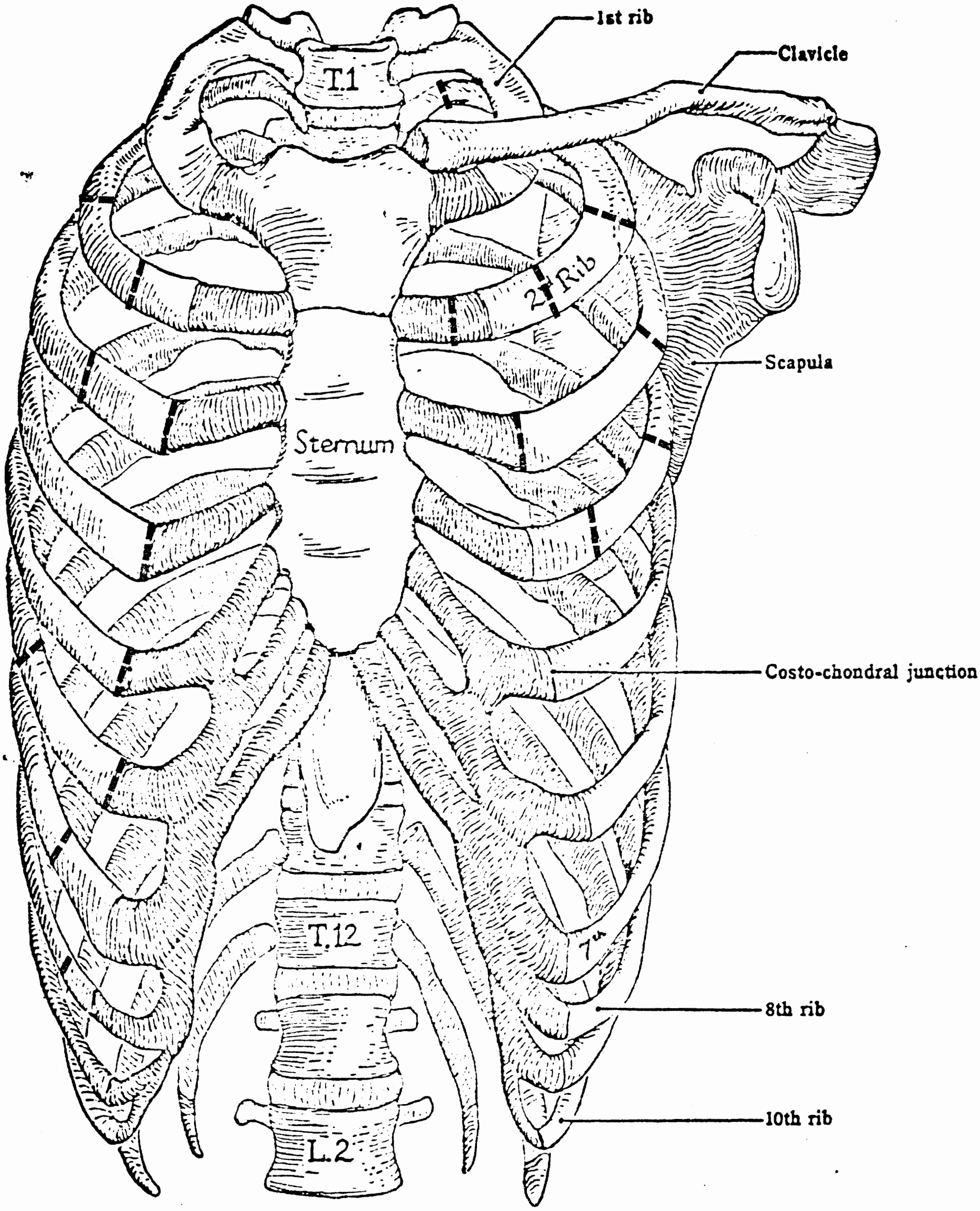
39.	Biacromial Diameter (A)		33.9
40.	Bideltoid Breadth (A)		41.0
41.	Chest Breadth at Axilla (A)		26.0
42.	Chest Breadth at Mid-Point between Suprasternale and Substernale		27.0
43.	Chest Breadth at Substernale (A)		29.7
44.	Hip Breadth, Iliocristale (A)		29.2
45.	Bispinous Diameter (A)		24.1
46.	ASIS to Symphysion Distance (A)	Rt.	13.9
		Lt.	14.0
47.	Bitrochanteric Diameter (A)		35.6
48.	Chest Depth at Suprasternale (A)		16.3
49.	Chest Depth at Axilla (A)		19.3
50.	Chest Depth at Nipple (A)		20.6
51.	Chest Depth at Substernale (A)		27.3
52.	Hip Depth, Iliocristale (A)		20.6
53.	ASIS Depth (A)	Rt.	15.6
		Lt.	17.0
54.	Buttocks Depth, Trochanterion (A)		
55.	Trochanterion	Rt.	
		Lt.	
56.	Symphysion (Hgt.)		
57.	Acromion-Radiale Length		32.9

Cad. I.D. 20218

58. Ball of Humerus - Radiale Length (A)	30.1
59. Radiale-Stylion Length (A)	23.7
60. Olecronan-Stylion Length (A)	24.9
61. Femur Length (A)	38.1
62. Tibia Length (A)	35.2
63. Fibula Length (A)	38.8
64. Upper Arm Depth, Mid Biceps (Sl.C.)	5.7
65. Humeral Biepicondylar Breadth (Sl.C.)	6.2
66. Forearm Depth (Sl.C.)	7.3
67. Wrist Depth (Sl.C.)	5.5
68. Hand Length (Sl.C.)	18.1
69. Hand Breadth (Sl.C.)	8.2
70. Hand Depth (Sl.C.)	3.1
71. Thigh Breadth, Mid-Thigh (Sl.C,)	11.5
72. Calf Depth (Sl.C.)	9.5
73. Bimalleolus Breadth (Sl. C.)	6.6
74. Foot Length (Sl.C.)	24.1
75. Foot Breadth (Sl.C.)	9.9

WHOLE BODY RESPONSE - WBR # 6

AUTOPSY RESULTS



Bony Thorax, anterior aspect

RIB FRACTURE SITES ARE INDICATED BY DASHED LINES (-----)

Other Injuries:

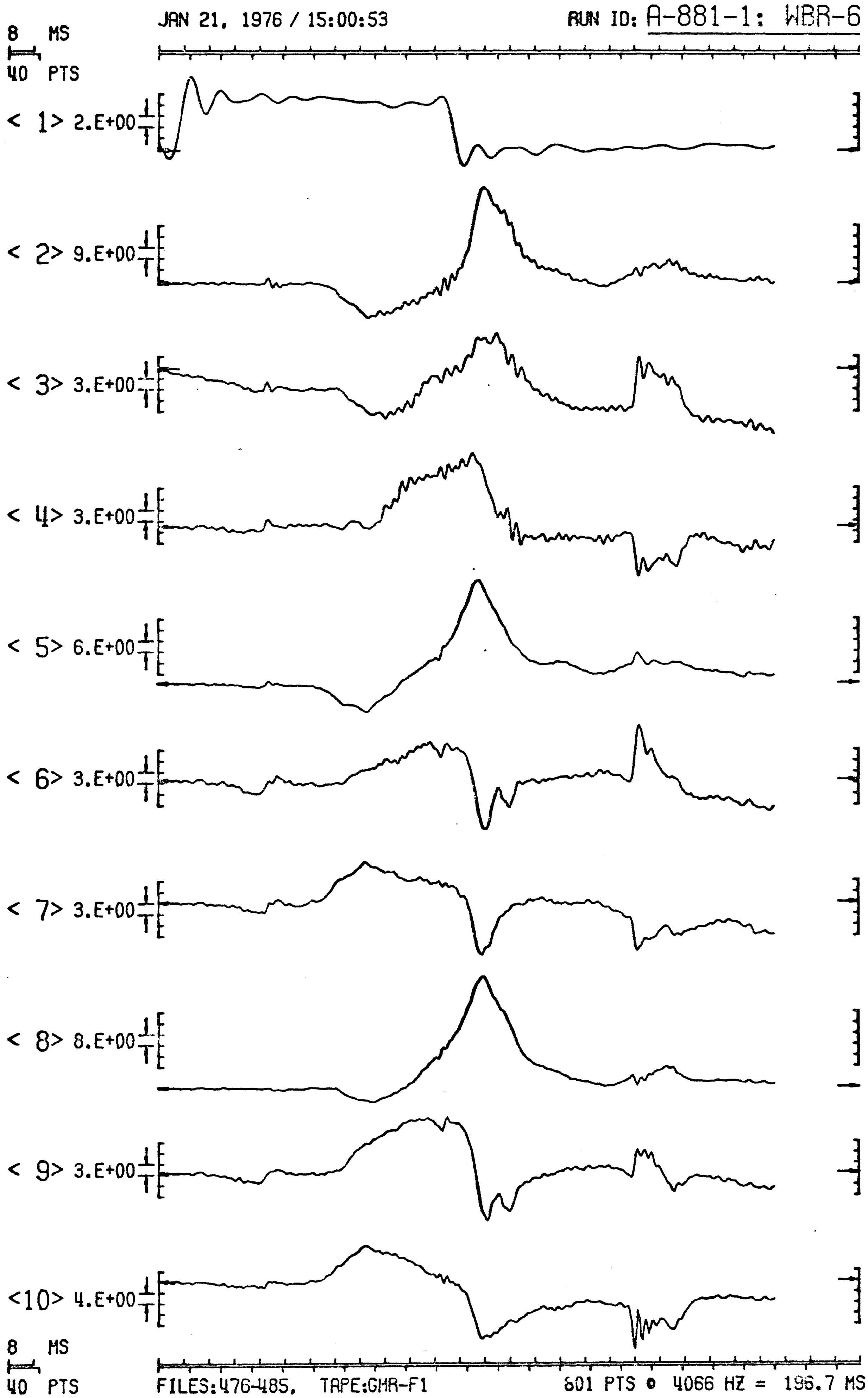
There was a long subcutaneous bruise with lacerations 6-7 cm long between rib 1 and 2. The lungs protruded. The tissue was full of fluid. Blood was found inside the pericardium.

TAPE: GMR-F1 | DIGITAL SIGNAL FILTERING JAN 21, 1976 03:22:01 | RUN ID: A-881-1: WBR-6

PROJECT: WHOLE BODY RESPONSE: CADAVER WBR-3 (9-ACC)

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
476 -	1:	SLED DECELERATION	G'S	801	4066.	LP(015-045)	(1)
477 -	2:	AX1 HEAD ACC (A)	G'S	801	4066.	LP(090-180)	(3)
478 -	3:	AY1 HEAD ACC (B)	G'S	801	4066.	LP(090-180)	(3)
479 -	4:	AZ1 HEAD ACC (C)	G'S	801	4066.	LP(090-180)	(3)
480 -	5:	AX2 HEAD ACC (C)	G'S	801	4066.	LP(090-180)	(3)
481 -	6:	AY2 HEAD ACC (A)	G'S	801	4066.	LP(090-180)	(3)
482 -	7:	AZ2 HEAD ACC (B)	G'S	801	4066.	LP(090-180)	(3)
483 -	8:	AX3 HEAD ACC (B)	G'S	801	4066.	LP(090-180)	(3)
484 -	9:	AY3 HEAD ACC (C)	G'S	801	4066.	LP(090-180)	(3)
485 -	10:	AZ3 HEAD ACC (A)	G'S	801	4066.	LP(090-180)	(3)
	11:						
	12:						

FILES: 476 - 485 ON TAPE: GMR-F1 RUN: A-881-1: WBR-6 FILTERED JAN 21, 1976 03:22:34


JAN 21, 1976 / 15:00:53
RUN ID: A-881-1: WBR-6
8 MS
40 PTS
< 1> 2.E+00
< 2> 9.E+00
< 3> 3.E+00
< 4> 3.E+00
< 5> 6.E+00
< 6> 3.E+00
< 7> 3.E+00
< 8> 8.E+00
< 9> 3.E+00
<10> 4.E+00
8 MS
40 PTS
FILES:476-485, TAPE:GMR-F1
801 PTS @ 4066 HZ = 196.7 MS

TAPE: GMR-F1

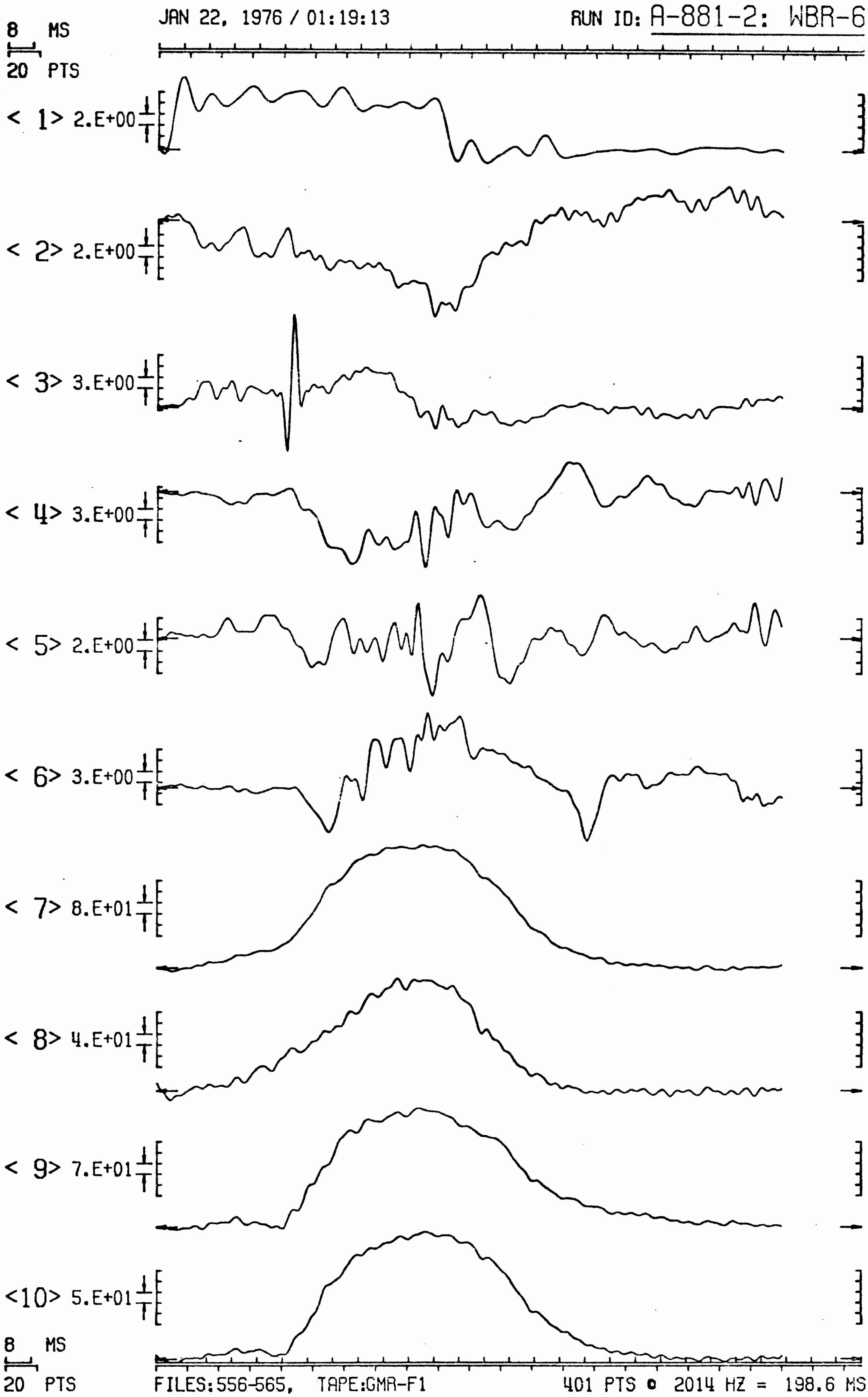
DIGITAL SIGNAL FILTERING
JAN 21, 1976   03:35:19

RUN ID: A-881-2: WBR-6

PROJECT: WHOLE BODY RESPONSE.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
556 -	1:	SLED DECELERATION	G'S	401	2014.	LP(030-000)	(4)
557 -	2:	PELVIS BIAX P-A ACC	G'S	401	2014.	LP(090-225)	(5)
558 -	3:	PELVIS BIAX I-S ACC	G'S	401	2014.	LP(090-225)	(5)
559 -	4:	THORAX TRIAX P-A ACC	G'S	401	2014.	LP(090-225)	(5)
560 -	5:	THORAX TRIAX I-S ACC	G'S	401	2014.	LP(090-225)	(5)
561 -	6:	THORAX TRIAX R-L ACC	G'S	401	2014.	LP(090-225)	(5)
562 -	7:	RIGHT LAP BELT LOAD	LBS	401	2014.	LP(090-225)	(5)
563 -	8:	LEFT LAP BELT LOAD	LBS	401	2014.	LP(090-225)	(5)
564 -	9:	UPPER SHOULDER BELT LOAD	LBS	401	2014.	LP(090-225)	(5)
565 -	10:	LOWER SHOULDER BELT LOAD	LBS	401	2014.	LP(090-225)	(5)
	11:						
	12:						

FILES: 556 - 565 ON TAPE: GMR-F1   RUN: A-881-2: WBR-6   FILTERED JAN 21, 1976 03:35:51


JAN 22, 1976 / 01:19:13
RUN ID: A-881-2: WBR-6
8 MS
20 PTS
< 1> 2.E+00
< 2> 2.E+00
< 3> 3.E+00
< 4> 3.E+00
< 5> 2.E+00
< 6> 3.E+00
< 7> 8.E+01
< 8> 4.E+01
< 9> 7.E+01
<10> 5.E+01
8 MS
20 PTS
FILES:556-565, TAPE:GMR-F1
401 PTS @ 2014 HZ = 198.6 MS

TAPE: GMR-F1

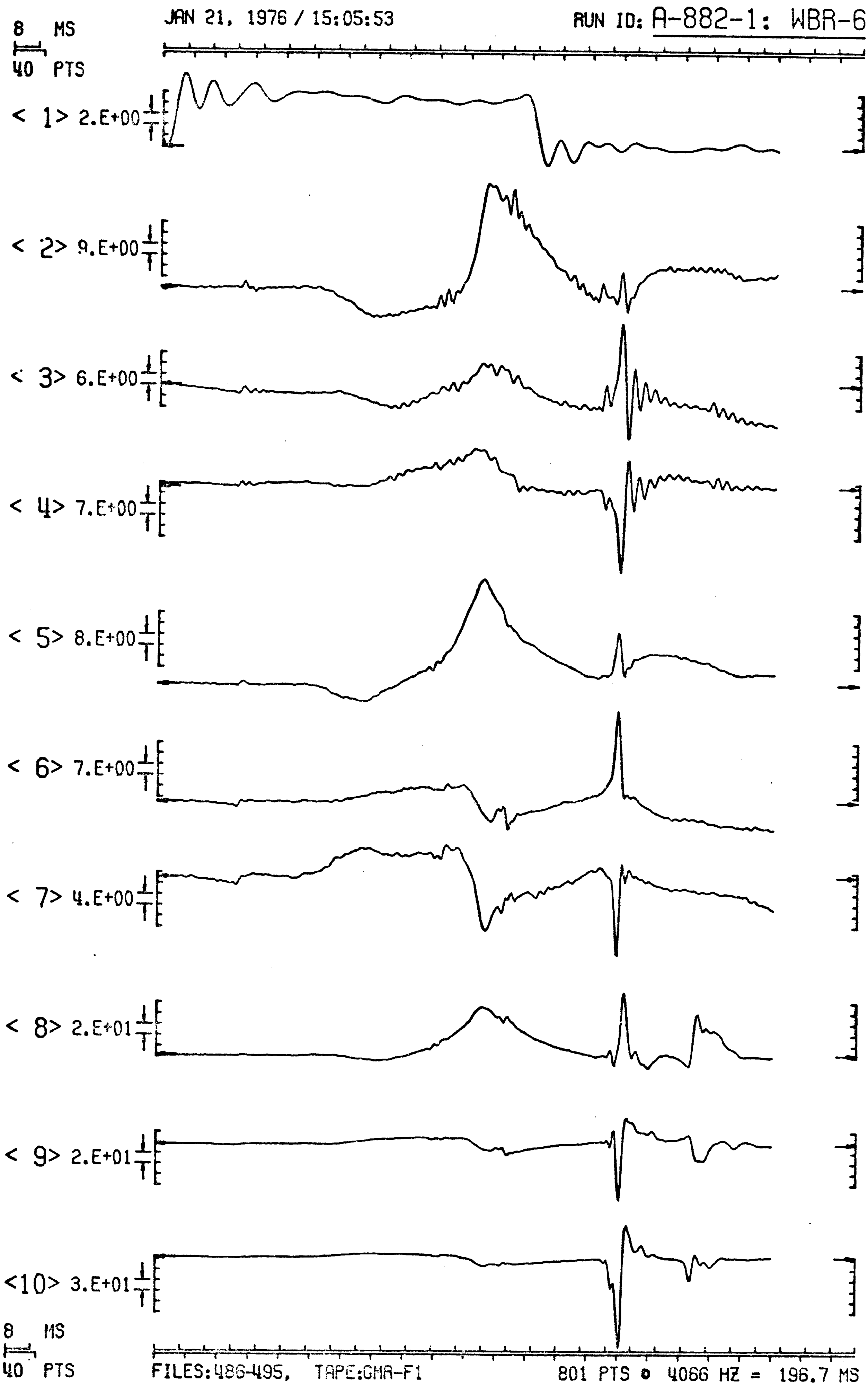
DIGITAL SIGNAL FILTERING
JAN 21, 1976 03:23:38

RUN ID: A-882-1: WBR-6

PROJECT: WHOLE BODY RESPONSE: CADAVER WBR-3 (9-ACC)

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
486 -	1:	SLED DECELERATION	G'S	801	4066.	LP(015-045)	(1)
487 -	2:	AX1 HEAD ACC (A)	G'S	801	4066.	LP(090-180)	(3)
488 -	3:	AY1 HEAD ACC (B)	G'S	801	4066.	LP(090-180)	(3)
489 -	4:	AZ1 HEAD ACC (C)	G'S	801	4066.	LP(090-180)	(3)
490 -	5:	AX2 HEAD ACC (C)	G'S	801	4066.	LP(090-180)	(3)
491 -	6:	AY2 HEAD ACC (A)	G'S	801	4066.	LP(090-180)	(3)
492 -	7:	AZ2 HEAD ACC (B)	G'S	801	4066.	LP(090-180)	(3)
493 -	8:	AX3 HEAD ACC (B)	G'S	801	4066.	LP(090-180)	(3)
494 -	9:	AY3 HEAD ACC (C)	G'S	801	4066.	LP(090-180)	(3)
495 -	10:	AZ3 HEAD ACC (A)	G'S	801	4066.	LP(090-180)	(3)
	11:						
	12:						

FILES: 486 - 495 ON TAPE: GMR-F1 RUN: A-882-1: WBR-6 FILTERED JAN 21, 1976 03:24:11


JAN 21, 1976 / 15:05:53
RUN ID: A-882-1: WBR-6
8 MS
40 PTS
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< 2> 9.E+00
< 3> 6.E+00
< 4> 7.E+00
< 5> 8.E+00
< 6> 7.E+00
< 7> 4.E+00
< 8> 2.E+01
< 9> 2.E+01
<10> 3.E+01
8 MS
40 PTS
FILES:486-495, TAPE:CMA-F1
801 PTS @ 4066 HZ = 196.7 MS

TAPE: GMR-F1

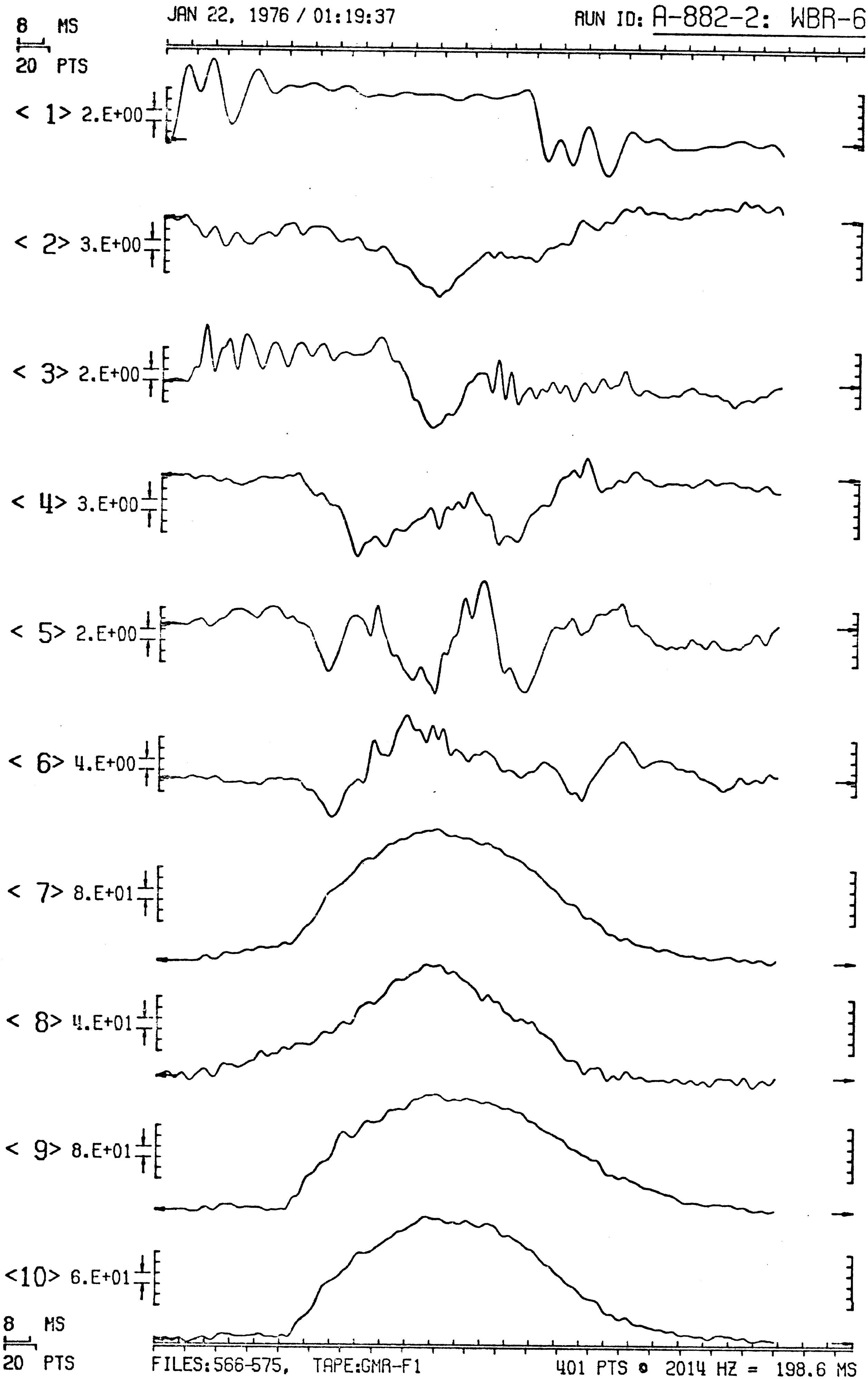
DIGITAL SIGNAL FILTERING
JAN 21, 1976 03:36:28

RUN ID: A-882-2: WBR-6

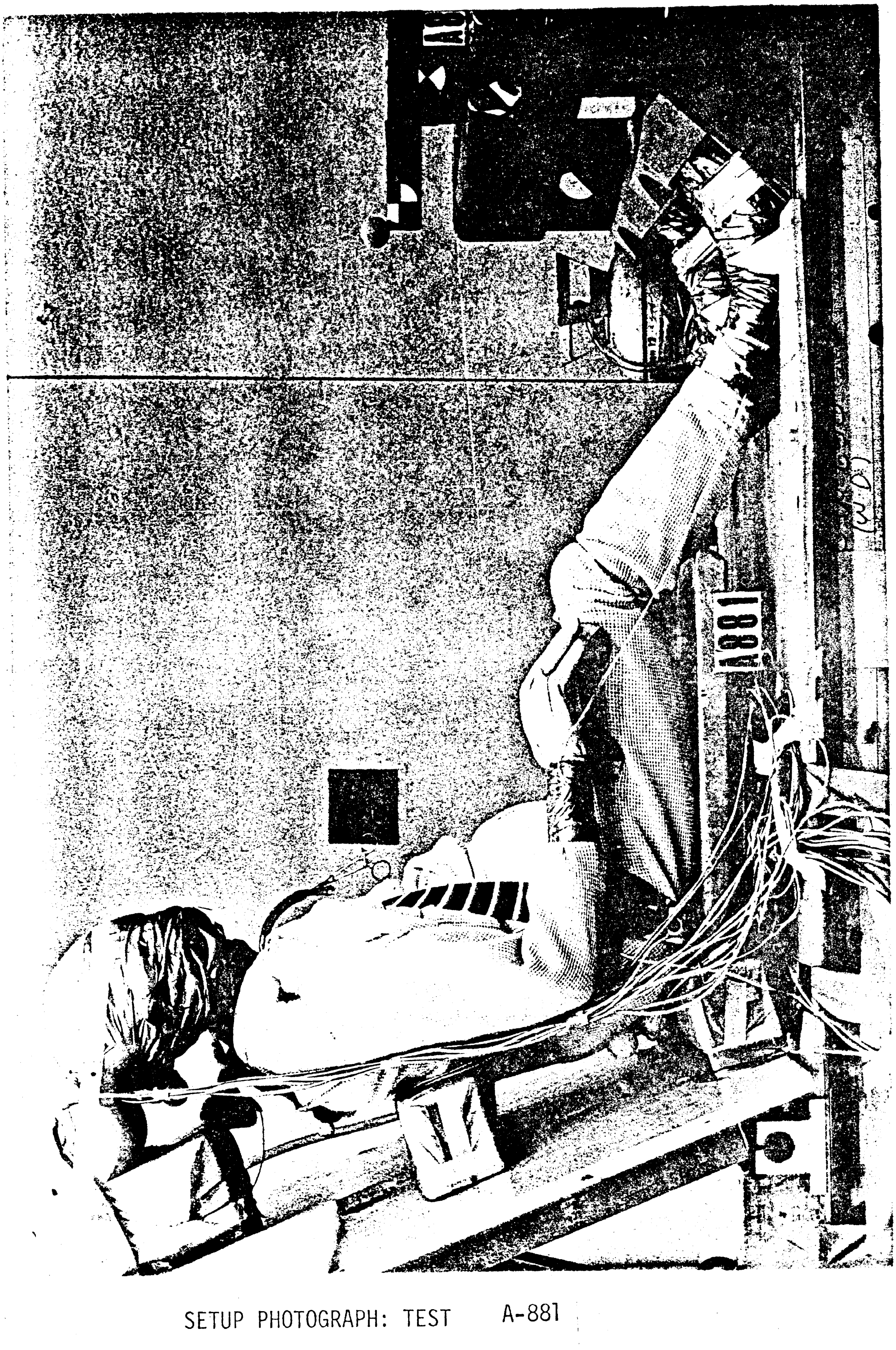
PROJECT: WHOLE BODY RESPONSE.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
566 -	1:	SLED DECELERATION	G'S	401	2014.	LP(030-090)	(4)
567 -	2:	PELVIS BIAX P-A ACC	G'S	401	2014.	LP(090-225)	(5)
568 -	3:	PELVIS BIAX I-S ACC	G'S	401	2014.	LP(090-225)	(5)
569 -	4:	THORAX TRIAX P-A ACC	G'S	401	2014.	LP(090-225)	(5)
570 -	5:	THORAX TRIAX I-S ACC	G'S	401	2014.	LP(090-225)	(5)
571 -	6:	THORAX TRIAX R-L ACC	G'S	401	2014.	LP(090-225)	(5)
572 -	7:	RIGHT LAP BELT LOAD	LBS	401	2014.	LP(090-225)	(5)
573 -	8:	LEFT LAP BELT LOAD	LBS	401	2014.	LP(090-225)	(5)
574 -	9:	UPPER SHOULDER BELT LOAD	LBS	401	2014.	LP(090-225)	(5)
575 -	10:	LOWER SHOULDER BELT LOAD	LBS	401	2014.	LP(090-225)	(5)
	11:						
	12:						

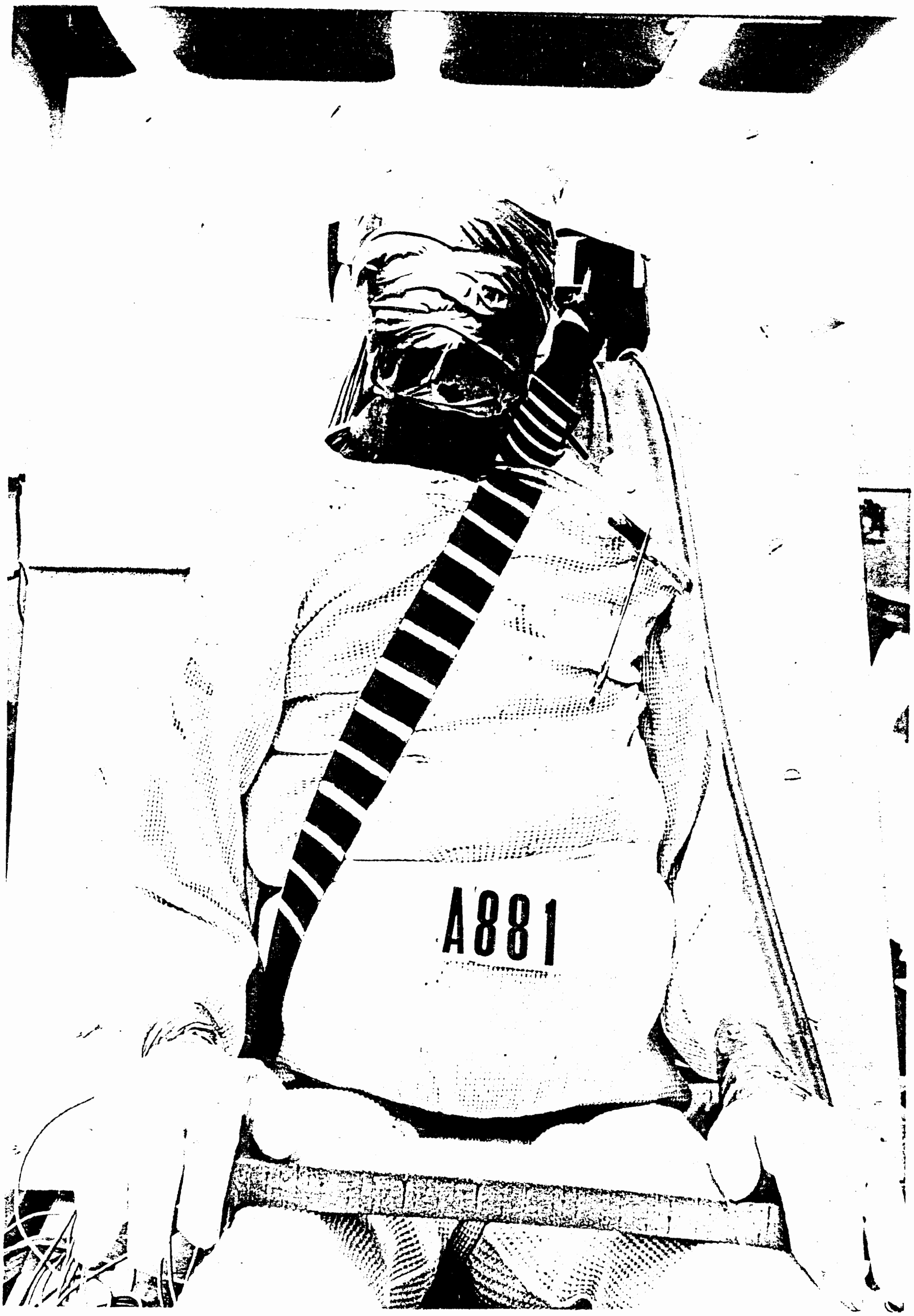
FILES: 566 - 575 ON TAPE: GMR-F1 RUN: A-882-2: WBR-6 FILTERED JAN 21, 1976 03:37:02



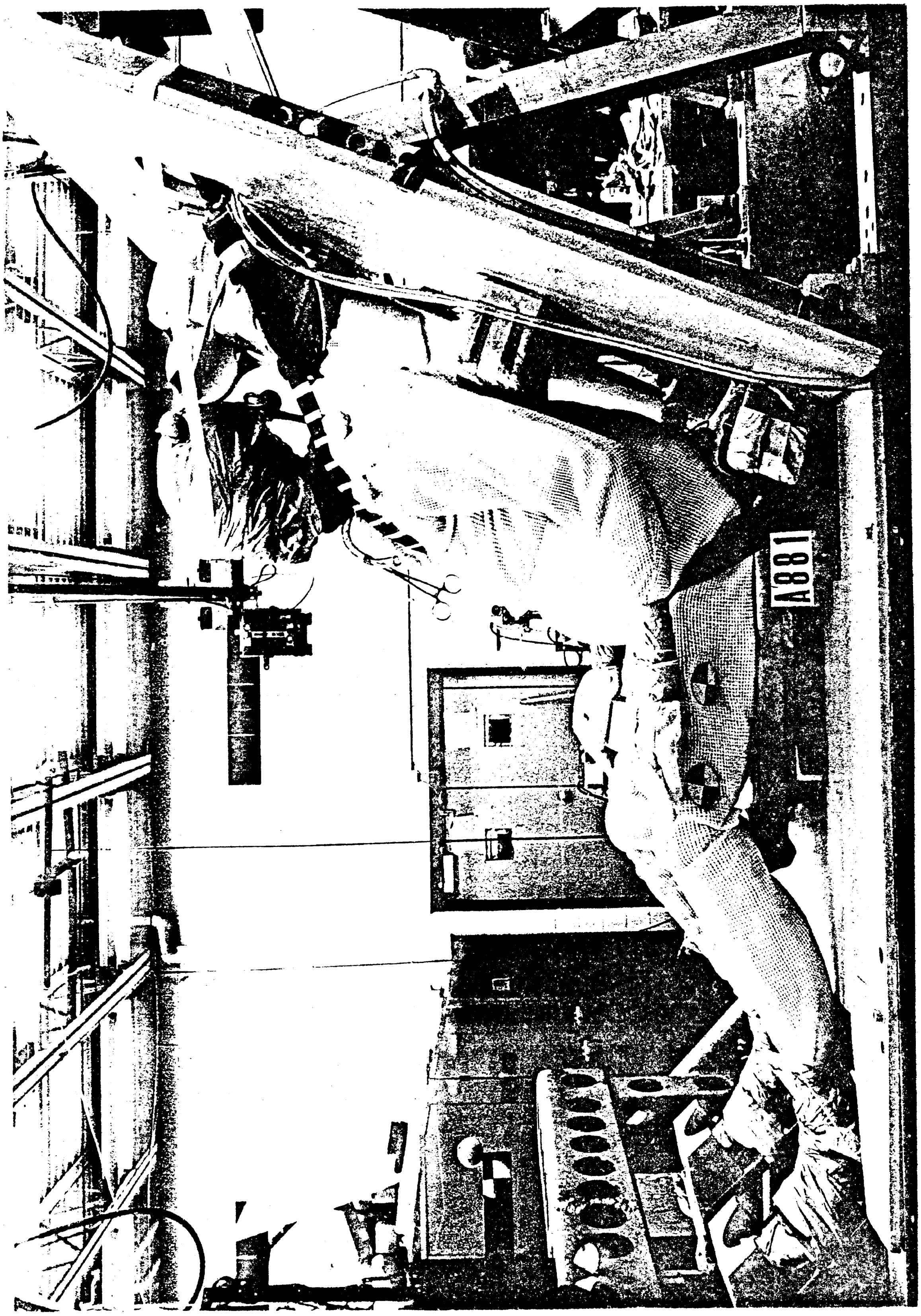
8 MS
20 PTS
JAN 22, 1976 / 01:19:37
RUN ID: A-882-2: WBR-6
< 1> 2.E+00
< 2> 3.E+00
< 3> 2.E+00
< 4> 3.E+00
< 5> 2.E+00
< 6> 4.E+00
< 7> 8.E+01
< 8> 4.E+01
< 9> 8.E+01
<10> 6.E+01
8 MS
20 PTS
FILES: 566-575, TAPE: GMR-F1
401 PTS @ 2014 HZ = 198.6 MS



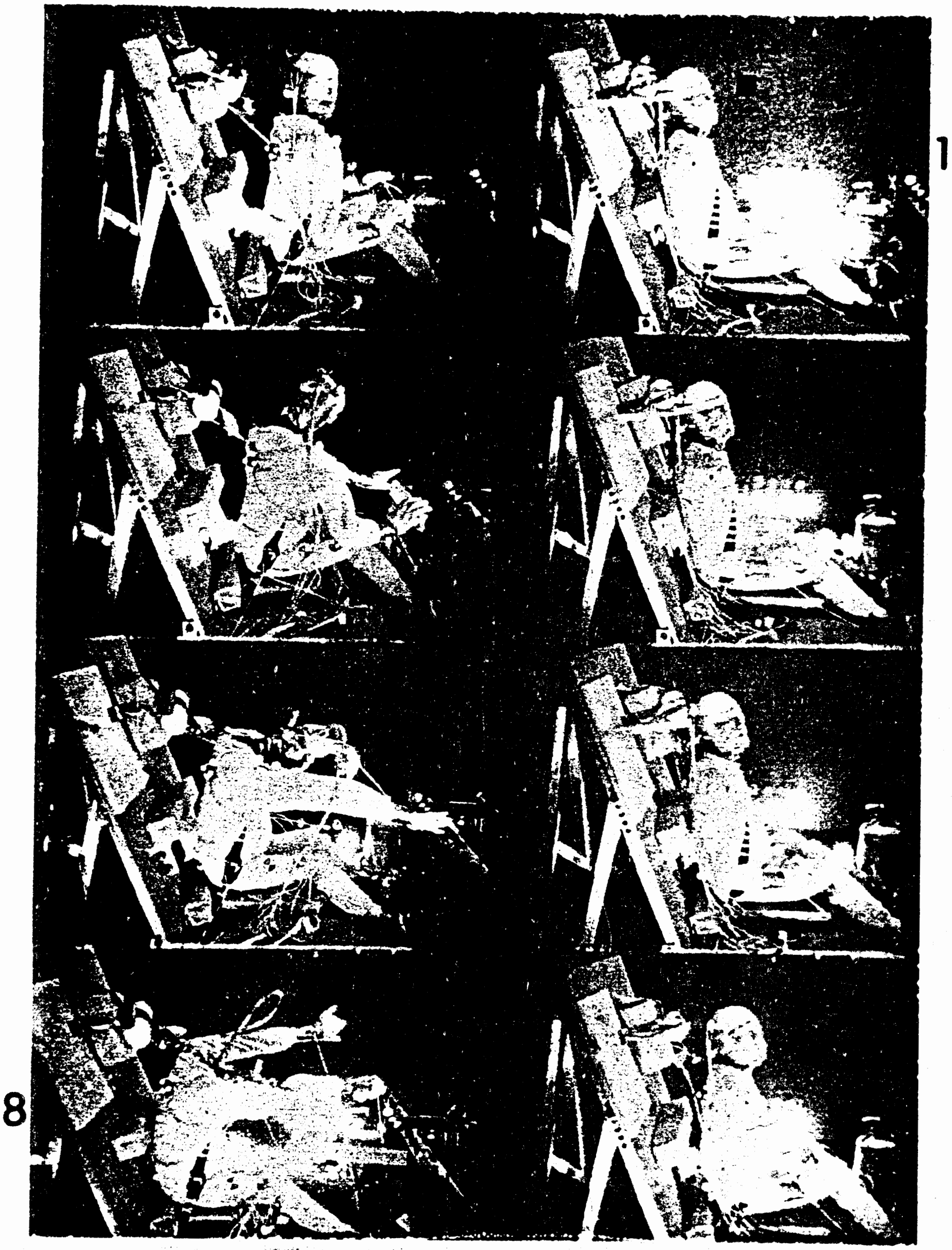
SETUP PHOTOGRAPH: TEST A-881



SETUP PHOTOGRAPH: TEST A-881

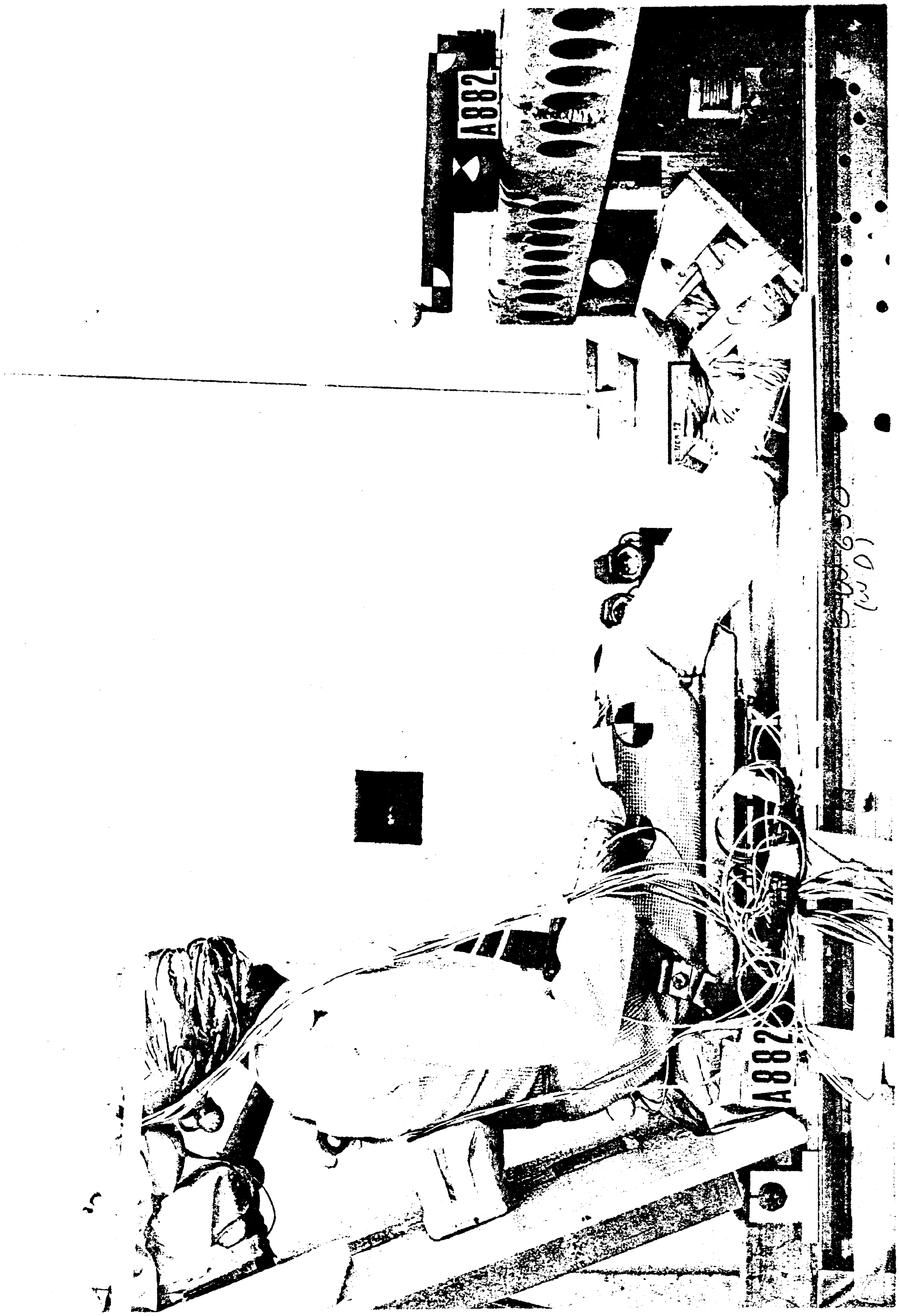


SETUP PHOTOGRAPH: TEST A-881



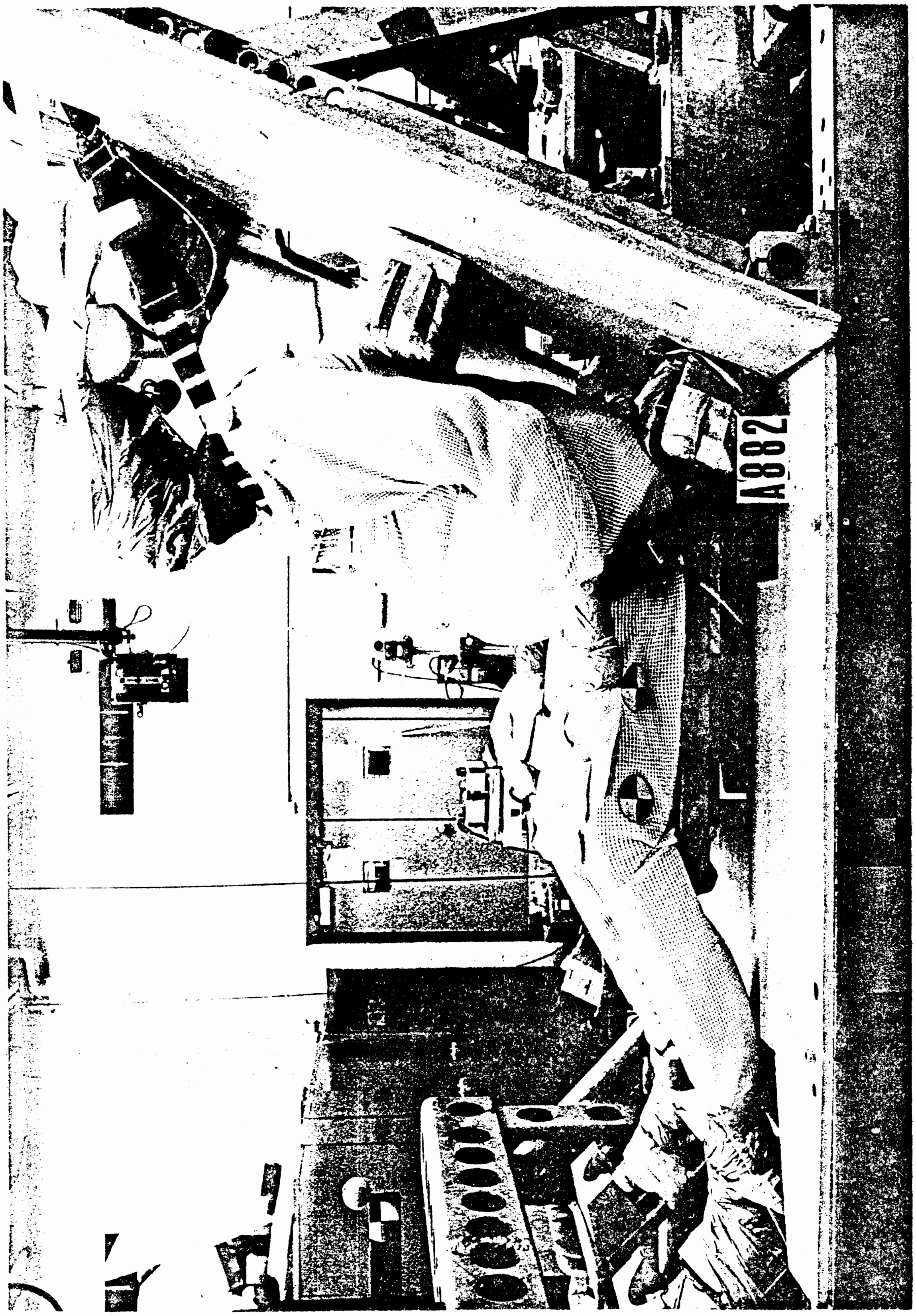
A 881

GRAPHCHECK PHOTOGRAPH: TEST | A-881

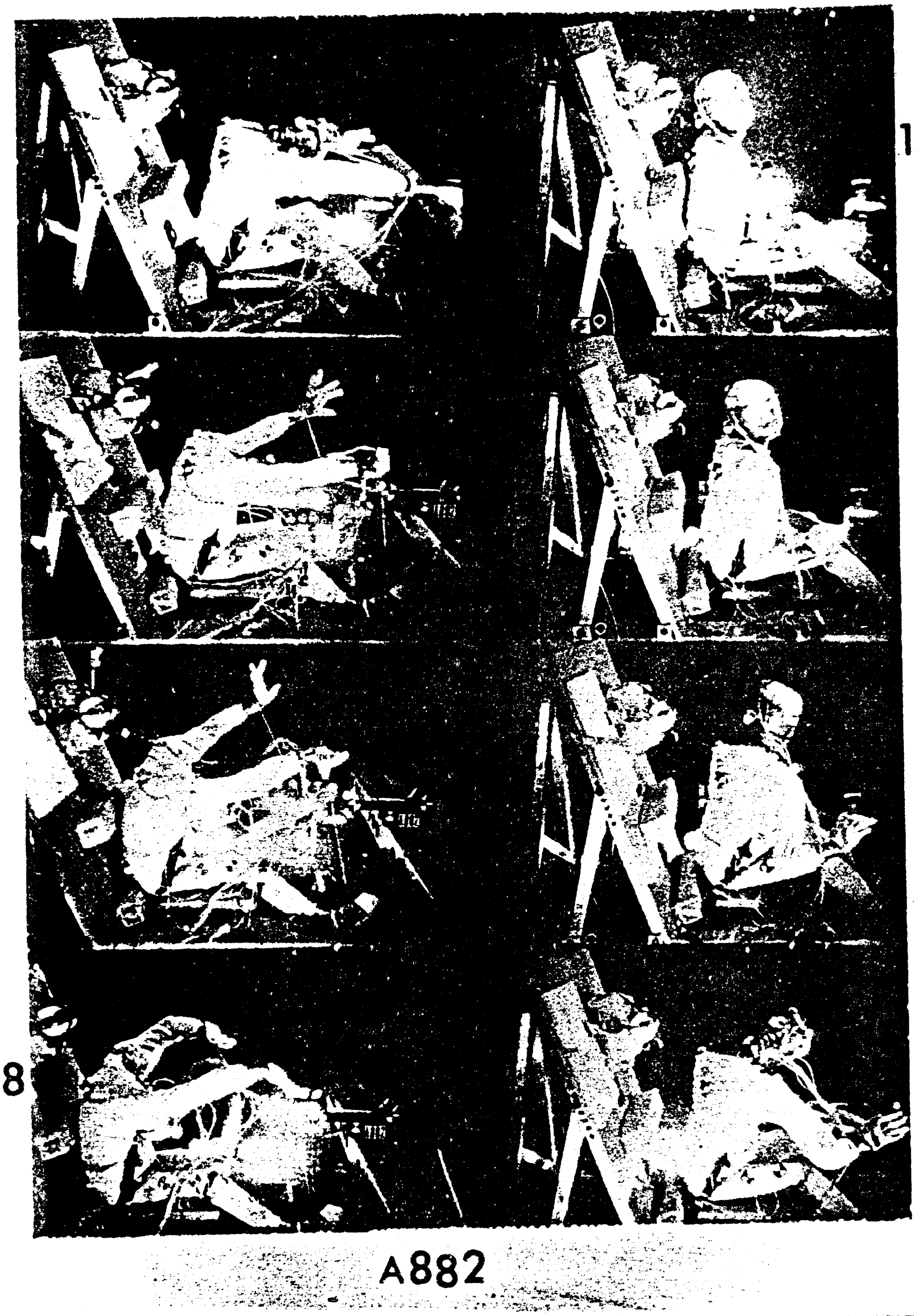


SETUP PHOTOGRAPH: TEST A-882

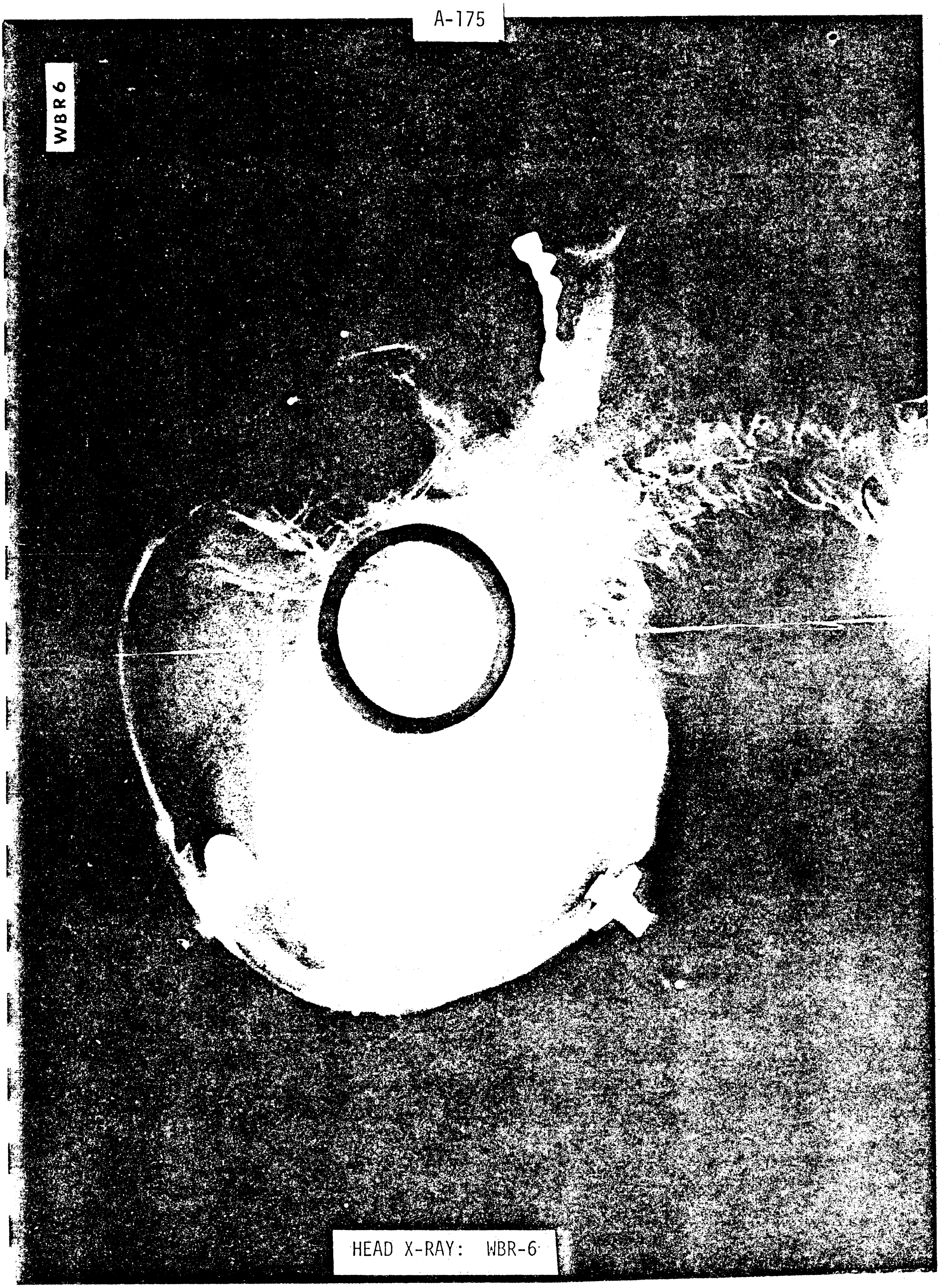
SETUP PHOTOGRAPH: TEST A-882



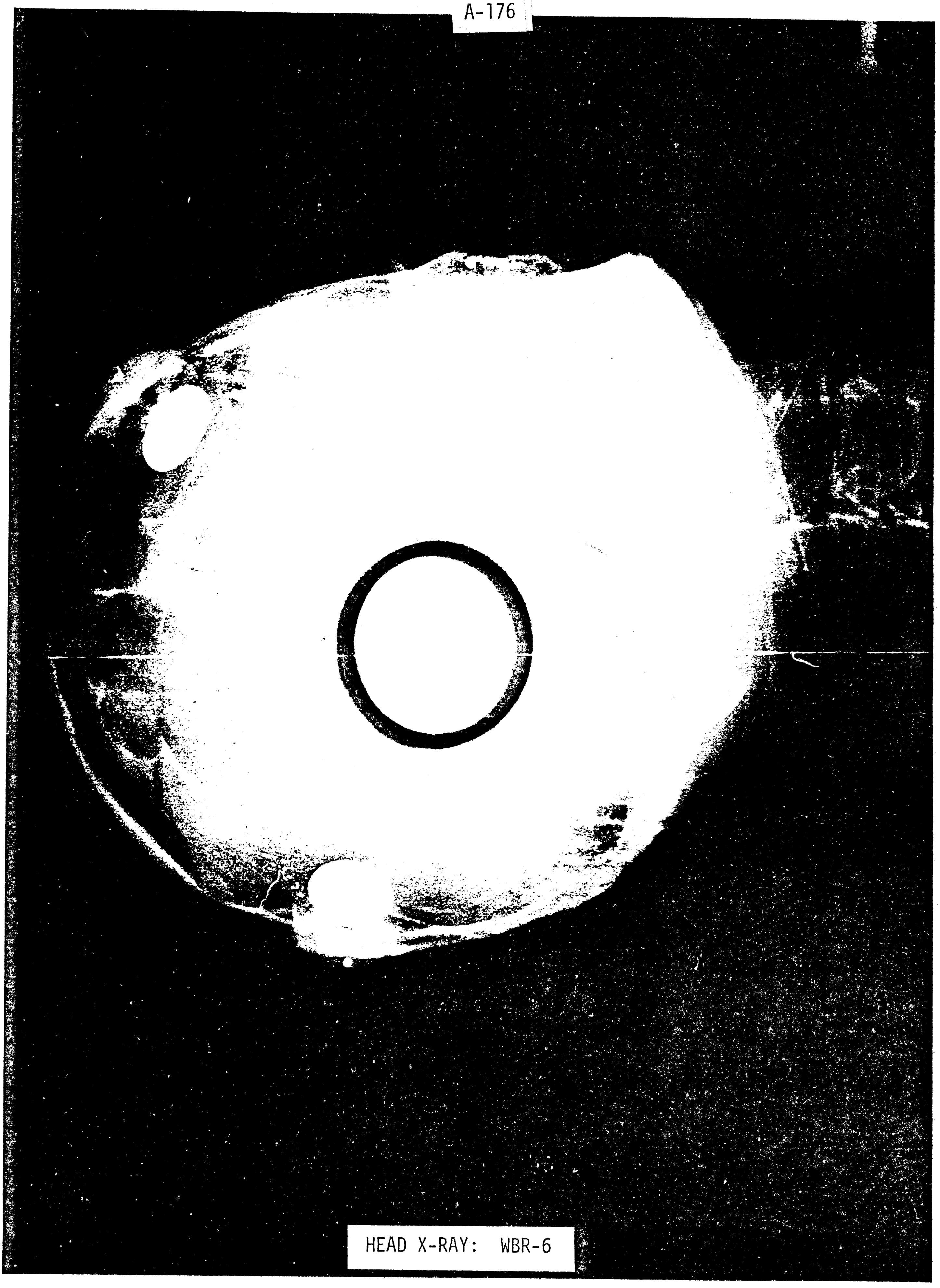
SETUP PHOTOGRAPH: TEST A-882



GRAPHCHECK PHOTOGRAPH: TEST A-882



HEAD X-RAY: WBR-6

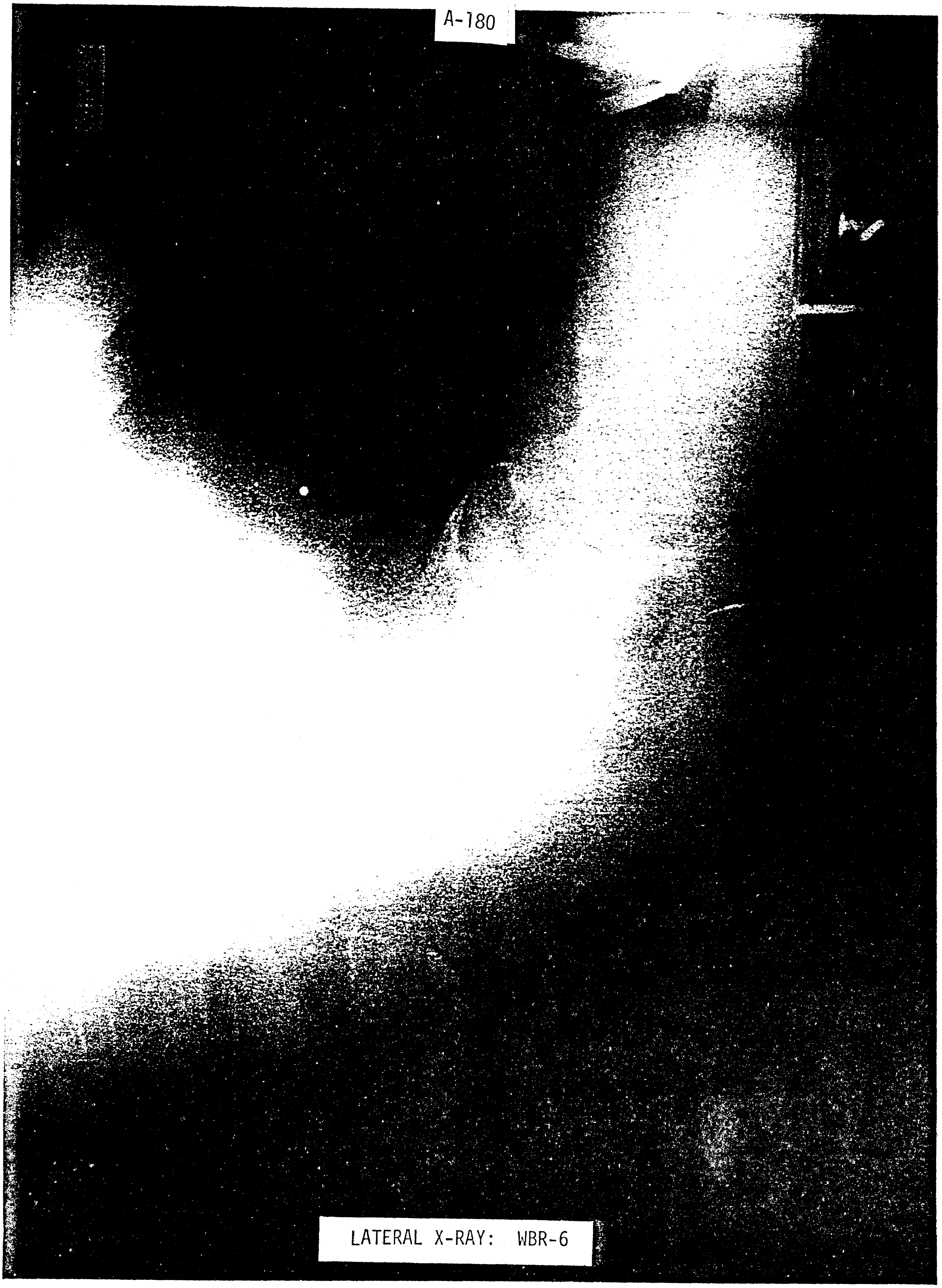


HEAD X-RAY: WBR-6

LATERAL X-RAY: WBR-6

LATERAL X-RAY: WBR-6

LATERAL X-RAY: WBR-6



LATERAL X-RAY: WBR-6

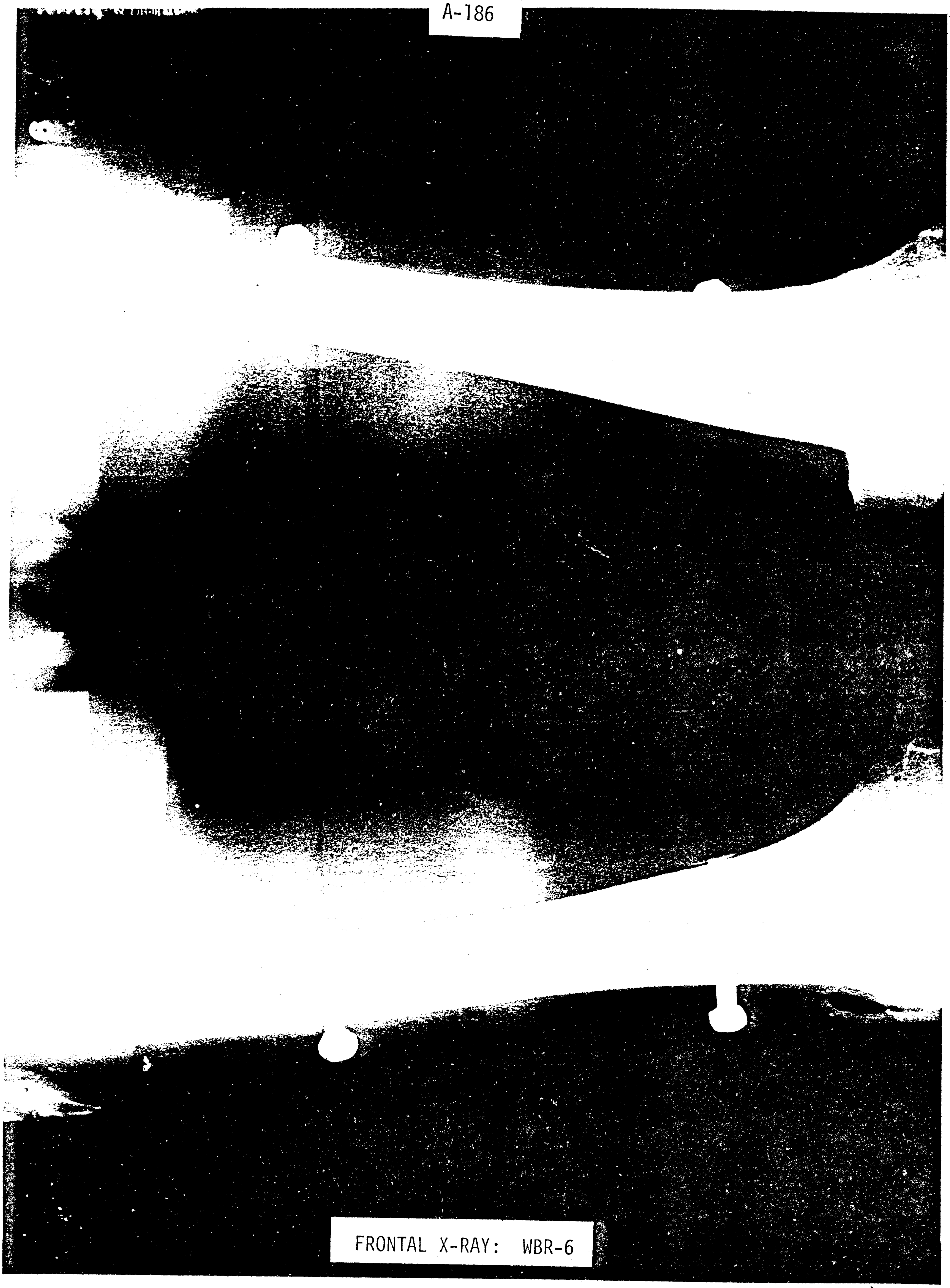
LATERAL X-RAY: WBR-6

LATERAL X-RAY: WBR-6

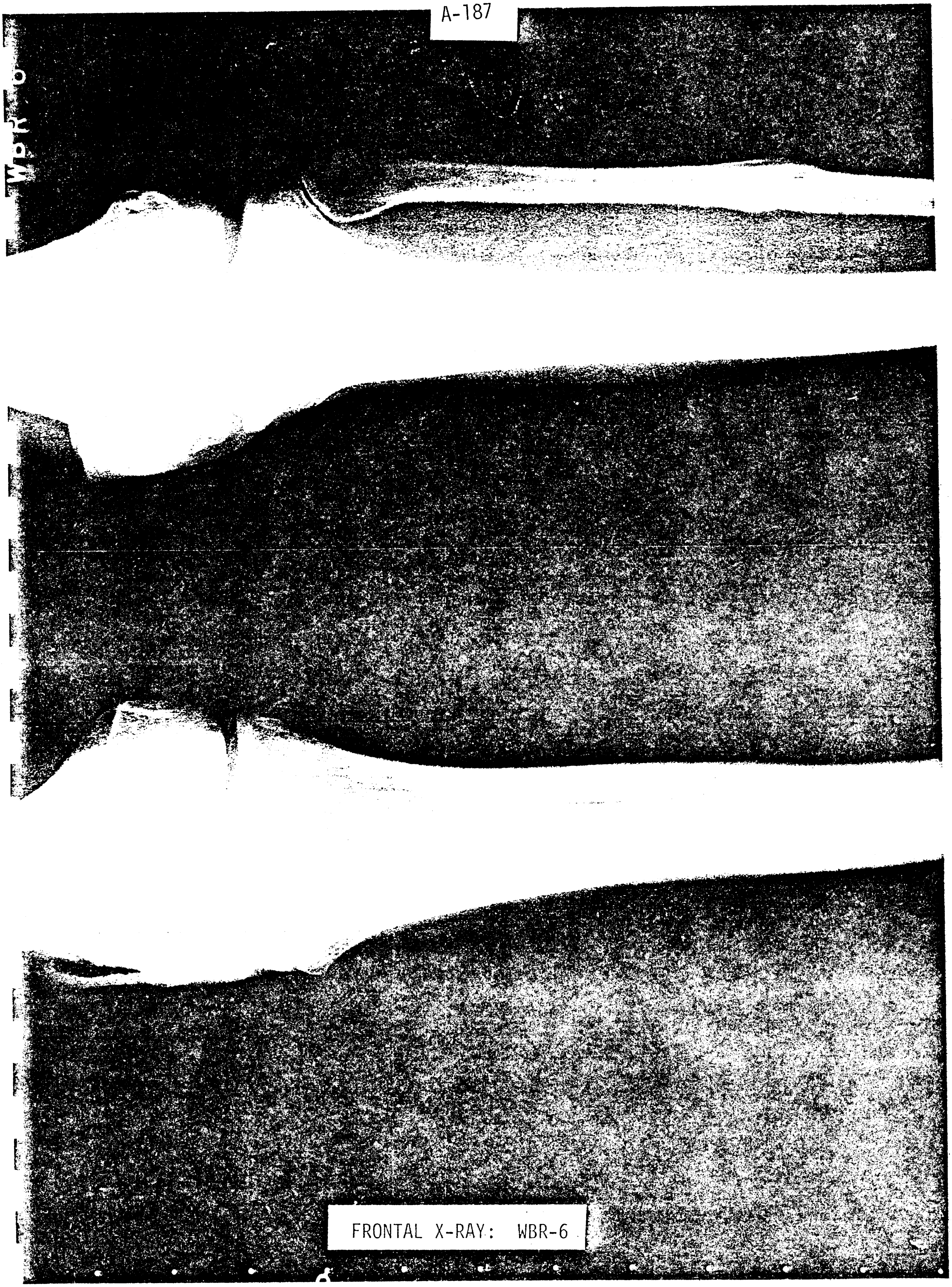
FRONTAL X-RAY: WBR-6

FRONTAL X-RAY: WBR-6

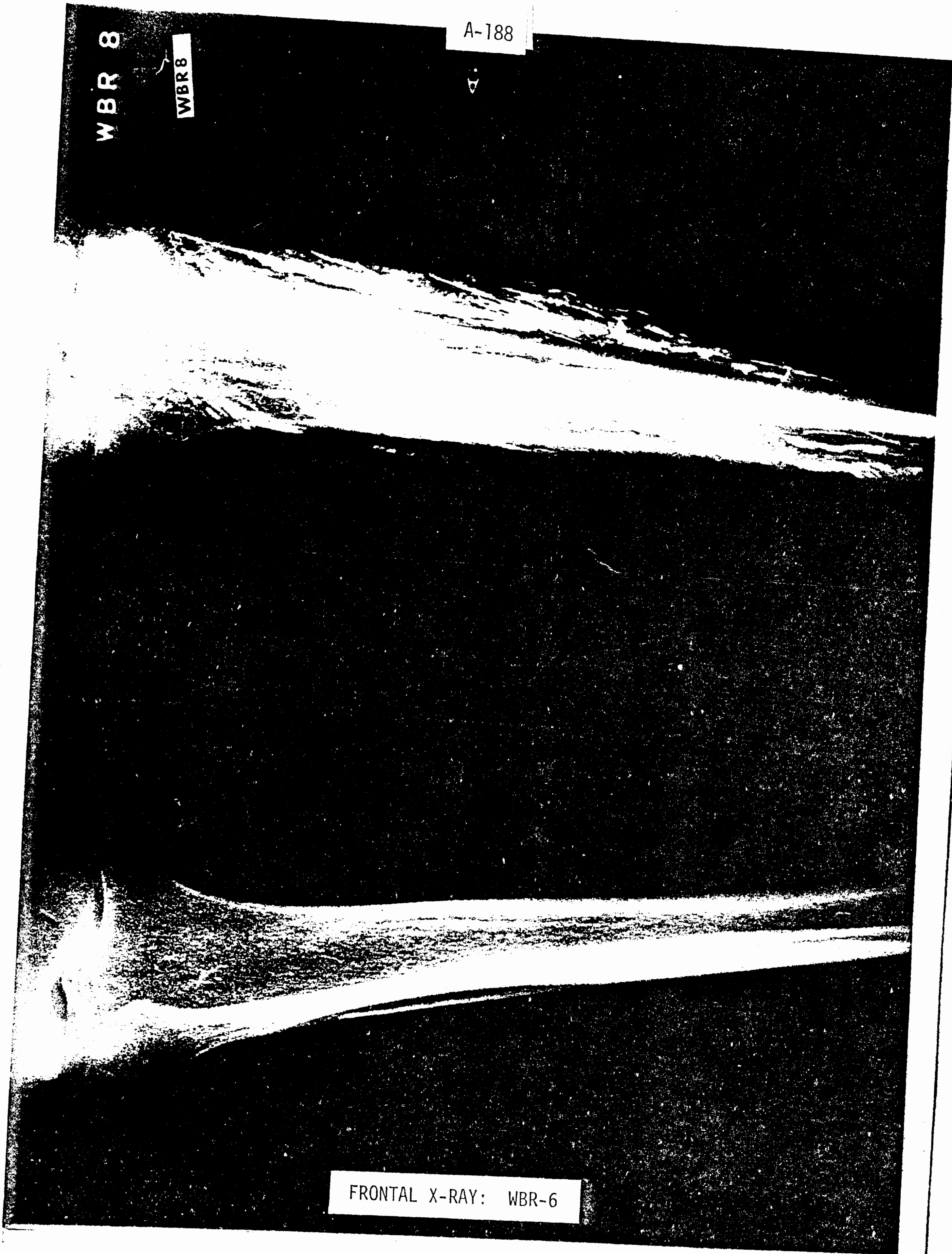
FRONTAL X-RAY: WBR-5



FRONTAL X-RAY: WBR-6



FRONTAL X-RAY: WBR-6



FRONTAL X-RAY: WBR-6

APPENDIX B

CERTIFIED DUMMY DATA PRESENTATION

APPENDIX B: CERTIFIED DUMMY DATA PRESENTATION

For each type of instrumentation, three different severity levels were tested using the same velocity and deceleration parameters as the equivalent cadaver tests (see Section 2.2). The certified dummy data is presented by severity level in the following sequence:

1. Lo-Severity
2. Intermediate Severity
3. Hi-Severity

For each severity level, the data will appear by test number in the following sequence:

SLED TEST SUMMARY

INSTRUMENTATION DATA SHEETS

BELT ANCHOR DATA

BELT LENGTH DATA

COMPUTER DATA PLOTS AND KEYS

SET-UP PHOTO PRINTS

GRAPH-CHECK PHOTO OF TEST

B.1 Type I Instrumentation

The certified dummy tests were run with two different instrumented configurations - type I consisted of the following:

1. Head C.G. Triaxial Accelerometer (inertial)
2. Chest C.G. Triaxial Accelerometer (inertial)
3. Pelvis C.G. Triaxial Accelerometer (inertial)
4. Femur Forces
5. Thorax Triaxial Accelerometer (Cadaver Type Installation)
6. Pelvis Biaxial Accelerometer (Cadaver Type Installation)
7. Four Belt Webbing Forces

The data follows:

WHOLE BODY RESPONSE

CERTIFIED DUMMY TEST

LOW Severity Impact

Type I Instrumentation

Frontal Impact

Three Point Belt Restraint

IMPACT PARAMETERS

TEST NO.	IMPACT VELOCITY (MPH)	IMPACT DECELERATION (G's)
A-888	16.6	10.2
A-889 (3" slack not in shoulder belt)	16.6	10.1
A-890	16.3	10.1
A-891	15.9	10.1

INSTRUMENTATION DATA SHEET

TEST NO. Certified Dummy   SLED RUN NO. A-888 to A-897   DATE 7-26-75   PREPARED BY ____________

TAPE DATA: RECORDER Honeywell   RECORD SPEED 30 IPS

	TAPE			TRANSDUCER			CALIBRATION						
CHAN.	INPUT	40% (3V) MODULATION VALUE	RUN GAIN	EXCIT. VOLT.	TYPE	S/N	CAL. RESISTOR	CAL. VOLTAGE	CAL. GAIN	CAL. VALUE	+ -	OUTPUT RUN SENSITIVITY	CHAN.
1	Sled Decel.	60 G	200	-	Stath	13587	-	1.1 2.2	1000	-		20 G/V	1
2	R. Femur	3000 #	200	VAR	G.S.E	021	50 K	2.08 200	200	2085#		1000 #/V	2
3	L. Femur	3000 #	100	VAR	G.S.E	020	50 K	2.09 200	200	2088#		1000 #/V	3
4	Chest A-P	178 G	100	-	Endev Triax	-	199.1 K	1.001	200	59.7G		59.6G/V	4
5	Chest S-I	194 G	100	-	"	-	199.1 K	1.001	200	64.9G		64.8G/V	5
6	Chest L-R	188 G	100	-	"	-	199.1 K	1.001	200	63.0G		62.9G/V	6
7	Pelvis S-I	207 G	100	-	"	-	199.1 K	.999	200	68.9G		69.0G/V	7
8	Pelvis A-P	162 G	100	-	"	-	199.1 K	.999	200	54.0G		54.1G/V	8
9	Pelvis L-R	185 G	100	-	"	-	199.1 K	1.001	200	62.0G		61.9G/V	9
10	Head A-P	189 G	100	-	"	-	199.1 K	1.000	200	63.2G		63.2G/V	10
11	Head S-I	197 G	100	-	"	-	199.1 K	1.000	200	65.7G		65.7G/V	11
12	Head L-R	207 G	100	-	"	-	199.1 K	1.000	200	69.1G		69.1G/V	12
13	Dig. Gate											280 ms	13
14	Time Base											.01 sec pulse	14

INSTRUMENTATION DATA SHEET

TEST NO. Certified Dummy SLED RUN NO. A-888 to A-897 DATE 7-26-75 PREPARED BY

TAPE DATA: RECORDER CEC : RECORD SPEED 30 IPS

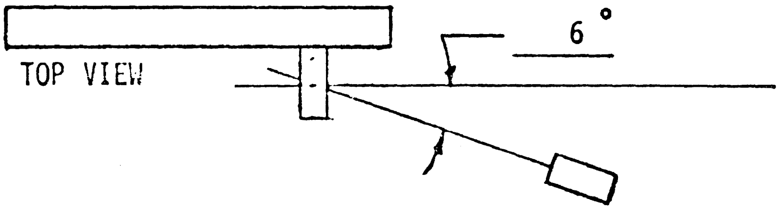
		TAPE		TRANSDUCER			CALIBRATION						
CHAN.	INPUT	40% (3V) MODULATION VALUE	RUN GAIN	EXCIT. VOLT.	TYPE	S/N	CAL. RESISTOR	CAL. VOLTAGE	CAL. GAIN	CAL. VALUE	±	OUTPUT RUN SENSITIVITY	CHAN.
1	Sled Decel.	60 G	200	--	Stath	13587	-	1.1 2.2	1000	--		.20 G/V	1
2	Pelvis P-A	151 G	100	10	Endev	AC04	199.4K	1.16	100	58.7G	-	50.6G/V	2
3	Pelvis I-S	151 G	100	10	"	AC06	199.5K	1.15	100	58.1G	+	50.5G/V	3
4	Thorax P-A	133 G	100	10	"	AC14	199.4K	1.16	100	51.6G	+	44.5G/V	4
5	Thorax I-S	159 G	100	10	"	AA49	199.2K	1.26	100	66.8G	-	53.0G/V	5
6	Thorax R-L	133 G	100	10	"	AA58	199.2K	1.26	100	56.2G	-	44.6G/V	6
7	Rt. Lap	3000 #	200	VAR	GSE	082	199.2K	2.20	200	2209#		1000 #/V	7
8	Lt. Lap	3000 #	200	VAR	"	083	50 K	2.24	200	2242#		1000 #/V	8
9	Up. Shldr.	3000 #	[illegible]	[illegible]	"	084	50 K	2.28	200	2277#		1000 #/V	9
10	Lo. Shldr.	3000 #	200	VAR	"	085	50 K	2.25	200	2245#		1000 #/V	10
11													11
12	Velocity											Fourth pulse is To	12
13	Dig. Gate											280 ms	13
14	Time Base											.01 sec pulse	14

WBR# Certified Dummy

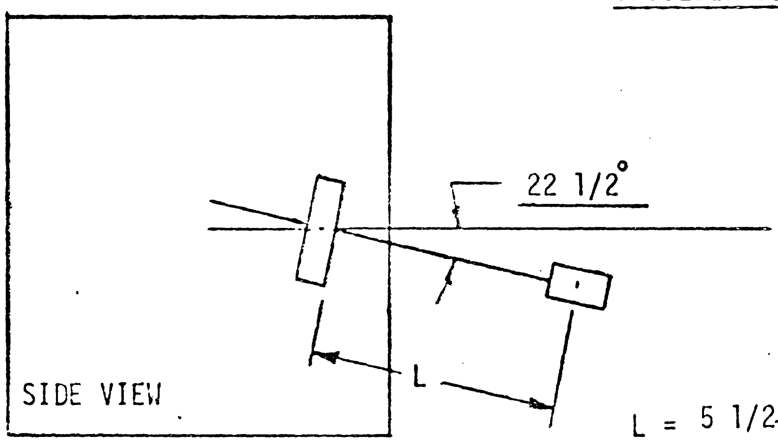
Test No. A-888

WHOLE BODY RESPONSE

BELT ANCHOR ORIENTATIONS

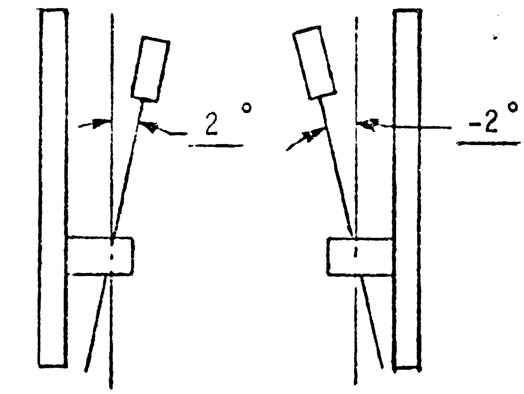


SHOULDER BELT



L = 5 1/2 in.

LAP BELT

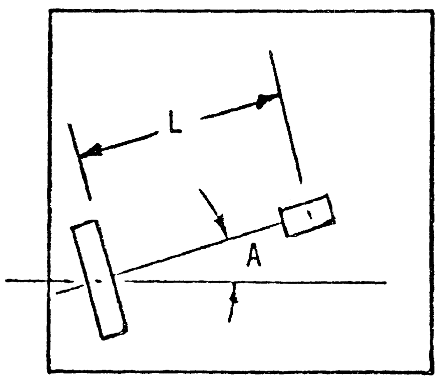


LEFT SIDE

RIGHT SIDE

TOP VIEW

(Sketch indicates Positive Angle directions)



SIDE VIEW

L_{LEFT} = 6 in.

L_{RIGHT} = 6 1/16 in.

A_{LEFT} = 53 1/2 °

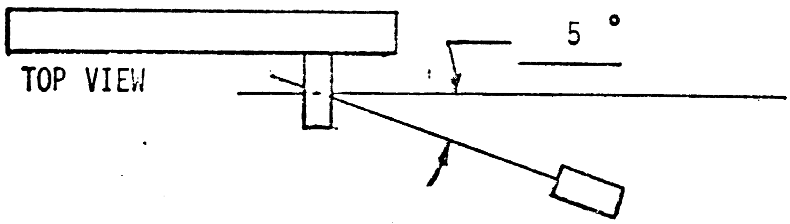
A_{RIGHT} = 59 °

WBR# Certified Dummy

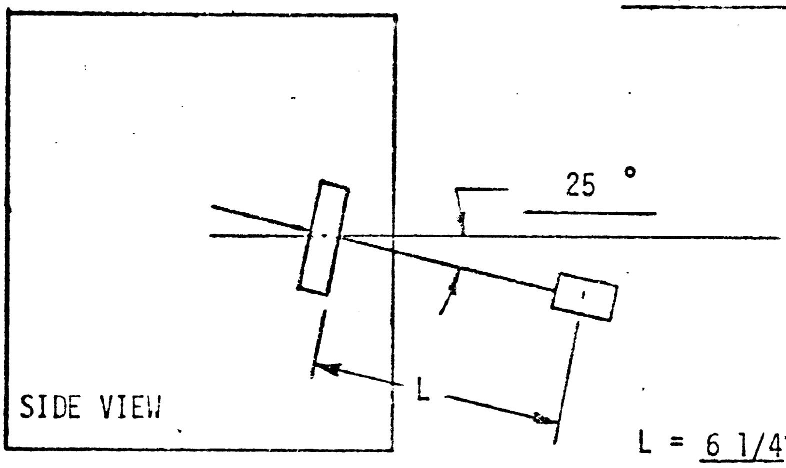
Test No. A-889

WHOLE BODY RESPONSE

BELT ANCHOR ORIENTATIONS

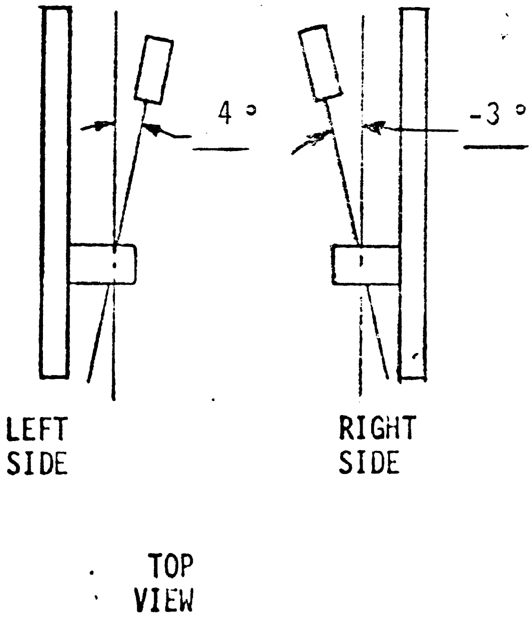


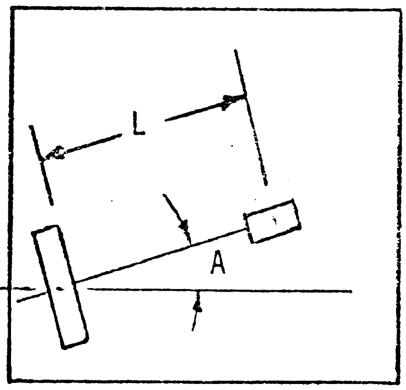
SHOULDER BELT



L = 6 1/4 in.

LAP BELT





SIDE VIEW

L_{LEFT} = 5 3/4 in.

L_{RIGHT} = 6 1/4 in.

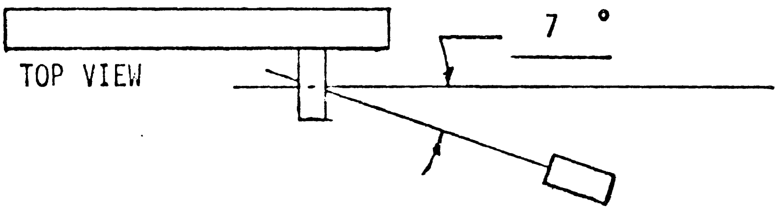
A_{LEFT} = 51 °

A_{RIGHT} = 61 °

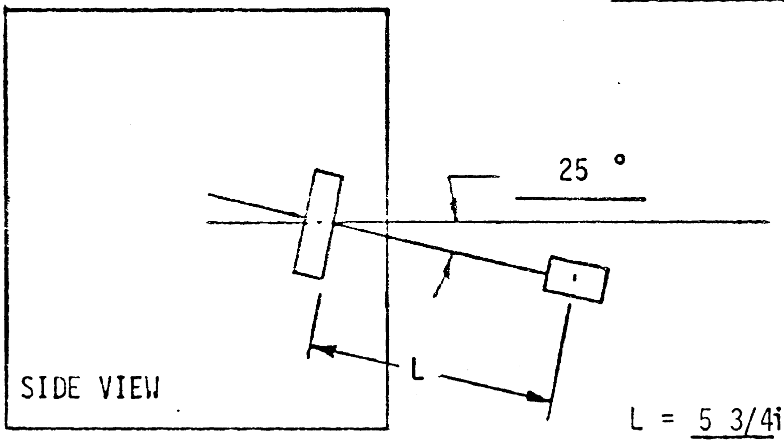
(Sketch indicates Positive Angle directions)

WHOLE BODY RESPONSE

BELT ANCHOR ORIENTATIONS

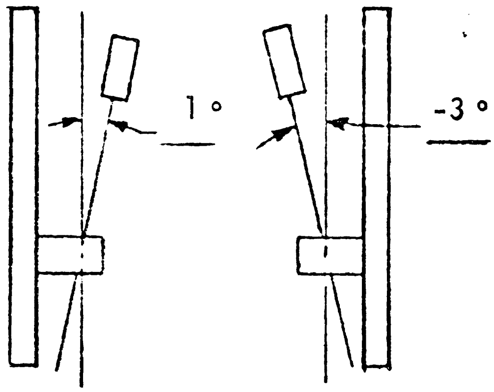


SHOULDER BELT



L = 5 3/4in.

LAP BELT

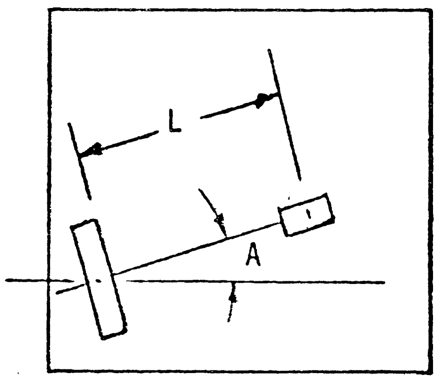


LEFT SIDE

RIGHT SIDE

TOP VIEW

(Sketch indicates Positive Angle directions)



SIDE VIEW

L_{LEFT} = 5 5/8 in.

L_{RIGHT} = 6 5/8 in.

A_{LEFT} = 52 °

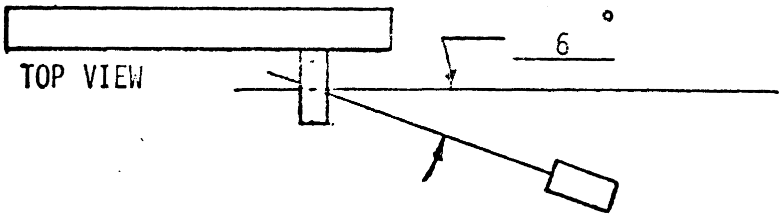
A_{RIGHT} = 60 °

WBR# Certified Dummy

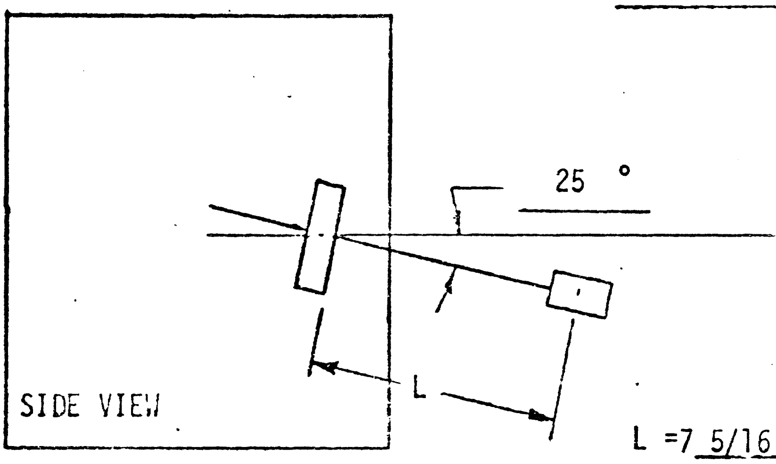
Test No. A-891

WHOLE BODY RESPONSE

BELT ANCHOR ORIENTATIONS

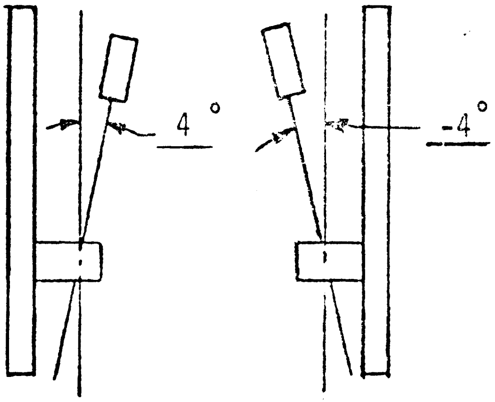


SHOULDER BELT

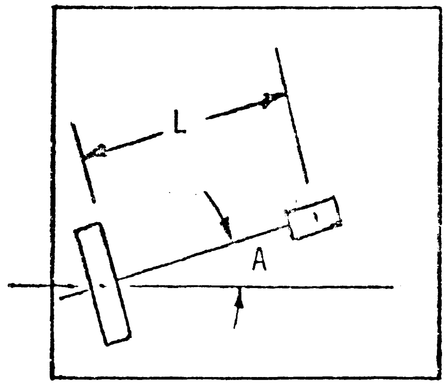


L =7 5/16 in.

LAP BELT



TOP VIEW



SIDE VIEW

L_{LEFT} = 6 1/16 in.

L_{RIGHT} = 5 11/16 in.

A_{LEFT} = 51 °

A_{RIGHT} = 56 °

(Sketch indicates Positive Angle directions)

WHOLE BODY RESPONSE WBR# Certified Dummy

BELT LENGTH DATA

TEST A- 888

Belt Position	Pre-Impact Length (in)	Post-Impact Length (in)	Belt Stretch (in)	Post-Impact Length with Load Cells
Rt. Lap	12	12	0	11 1/4
Lt. Lap	32 1/2	32 1/2	0	31 5/8
Shoulder	42	42	0	40 1/2

Test A- 889

Belt Position	Pre-Impact Length (in)	Post-Impact Length (in)	Belt Stretch (in)	Post-Impact Length with Load Cells
Rt. Lap	12	12	0	11 1/4
Lt. Lap	32 1/2	32 1/2	0	31 3/4
Shoulder	42	42	0	40 1/2

WHOLE BODY RESPONSE WBR# Certified Dummy

BELT LENGTH DATA

TEST A- 890

Belt Position	Pre-Impact Length (in)	Post-Impact Length (in)	Belt Stretch (in)	Post-Impact Length with Load Cells
Rt. Lap	12	12	0	11 1/8
Lt. Lap	32 1/2	32 1/2	0	31 3/4
Shoulder	42	42 1/8	1/8	40 3/8

Test A- 891

Belt Position	Pre-Impact Length (in)	Post-Impact Length (in)	Belt Stretch (in)	Post-Impact Length with Load Cells
Rt. Lap	12	12	0	11 3/8
Lt. Lap	32 1/2	32 1/2	0	31 3/4
Shoulder	42	42 1/8	1/8	40 1/2

TAPE: GMR-F1

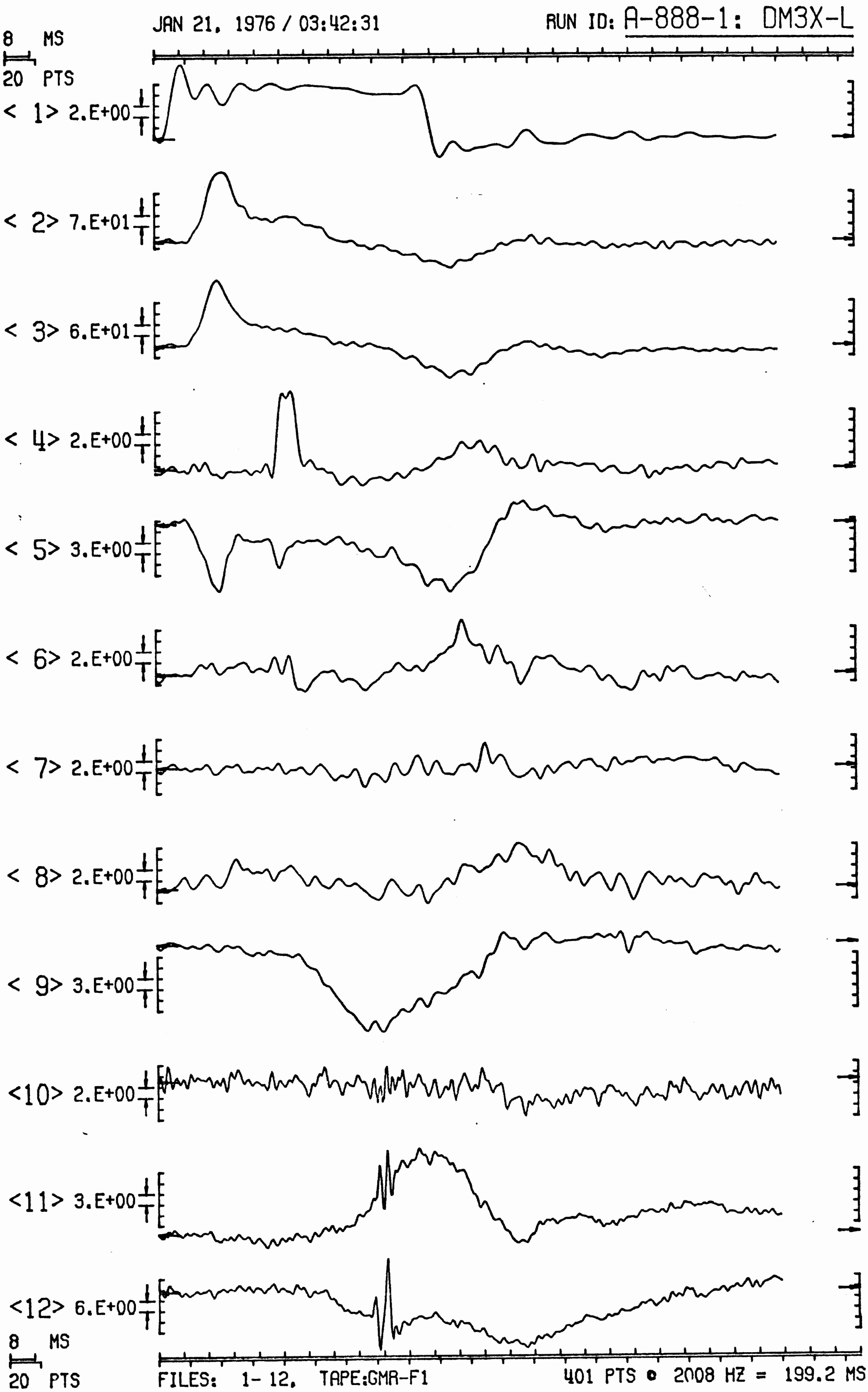
DIGITAL SIGNAL FILTERING
JAN 21, 1976 01:34:21

RUN ID: A-888-1: DM3X-L

PROJECT: WHOLE BODY RESPONSE: DUMMY WITH TRIAXIALS AND BIAXIALS.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
1 -	1:	SLED DECELERATION	G'S	401	2008.	LP(030-090)	(4)
2 -	2:	RIGHT FEMUR LOAD	LBS	401	2008.	LP(090-225)	(5)
3 -	3:	LEFT FEMUR LOAD	LBS	401	2008.	LP(090-225)	(5)
4 -	4:	CHEST TRIAX P-A ACC	G'S	401	2008.	LP(090-225)	(5)
5 -	5:	CHEST TRIAX I-S ACC	G'S	401	2008.	LP(090-225)	(5)
6 -	6:	CHEST TRIAX R-L ACC	G'S	401	2008.	LP(090-225)	(5)
7 -	7:	PELVIS TRIAX I-S ACC	G'S	401	2008.	LP(090-225)	(5)
8 -	8:	PELVIS TRIAX P-A ACC	G'S	401	2008.	LP(090-225)	(5)
9 -	9:	PELVIS TRIAX R-L ACC	G'S	401	2008.	LP(090-225)	(5)
10 -	10:	HEAD TRIAX P-A ACC	G'S	401	2008.	LP(180-360)	(6)
11 -	11:	HEAD TRIAX I-S ACC	G'S	401	2008.	LP(180-360)	(6)
12 -	12:	HEAD TRIAX R-L ACC	G'S	401	2008.	LP(180-360)	(6)

FILES: 1 - 12 ON TAPE: GMR-F1 RUN: A-888-1: DM3X-L FILTERED JAN 21, 1976 01:35:05


JAN 21, 1976 / 03:42:31
RUN ID: A-888-1: DM3X-L
8 MS
20 PTS
< 1> 2.E+00
< 2> 7.E+01
< 3> 6.E+01
< 4> 2.E+00
< 5> 3.E+00
< 6> 2.E+00
< 7> 2.E+00
< 8> 2.E+00
< 9> 3.E+00
<10> 2.E+00
<11> 3.E+00
<12> 6.E+00
8 MS
20 PTS
FILES: 1- 12, TAPE:GMR-F1
401 PTS @ 2008 HZ = 199.2 MS

TAPE: GMR-F1

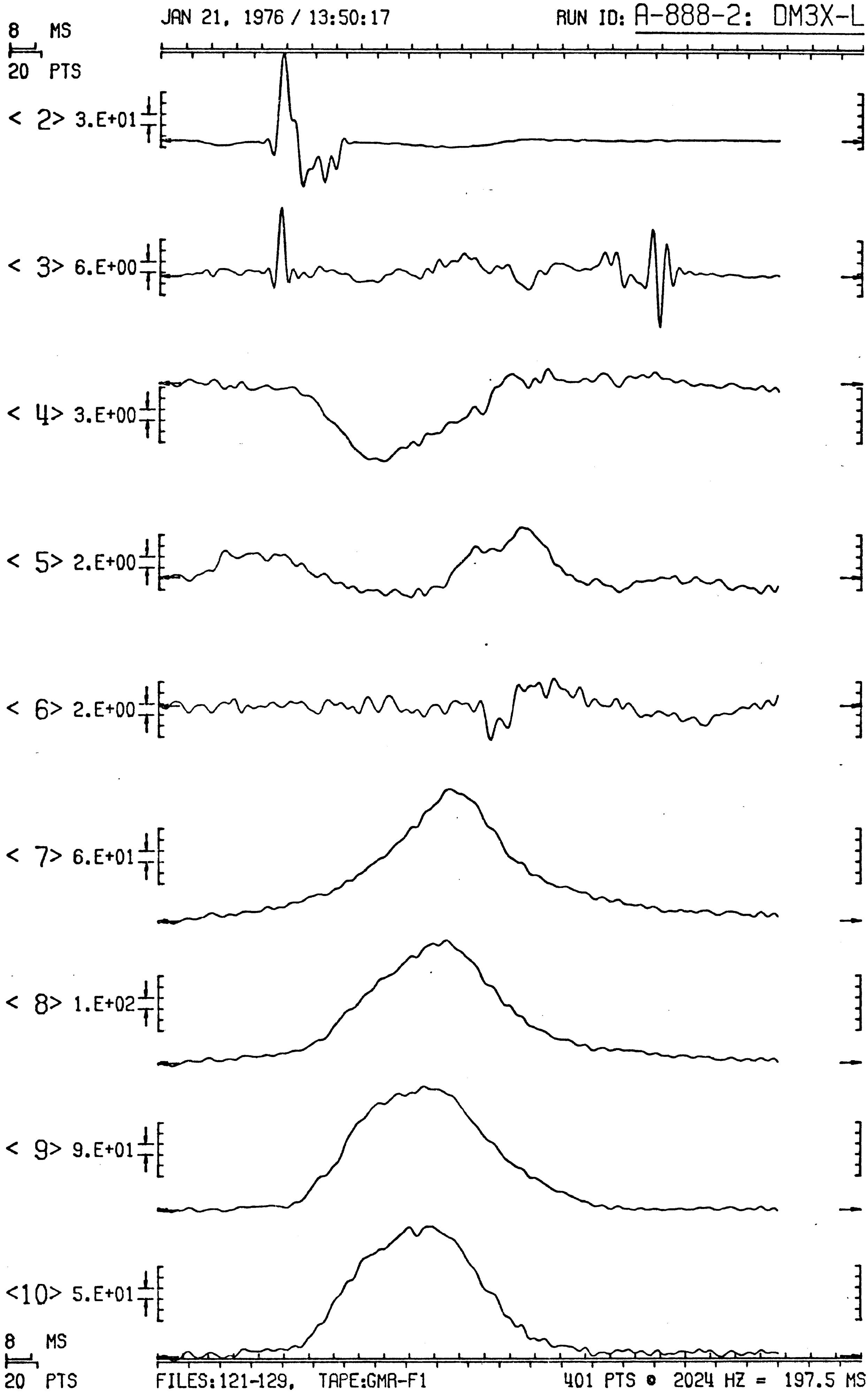
DIGITAL SIGNAL FILTERING
JAN 21, 1976 02:07:28

RUN ID: A-888-2: DM3X-L

PROJECT: WHOLE BODY RESPONSE.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
	1:						
121 -	2:	PELVIS EXT A-P ACC	G'S	401	2025.	LP(090-225)	(5)
122 -	3:	PELVIS EXT S-I ACC	G'S	401	2025.	LP(090-225)	(5)
123 -	4:	THORAX EXT A-P ACC	G'S	401	2025.	LP(090-225)	(5)
124 -	5:	THORAX EXT S-I ACC	G'S	401	2025.	LP(090-225)	(5)
125 -	6:	THORAX EXT L-R ACC	G'S	401	2025.	LP(090-225)	(5)
126 -	7:	RIGHT LAP BELT LOAD	LBS	401	2025.	LP(090-225)	(5)
127 -	8:	LEFT LAP BELT LOAD	LBS	401	2025.	LP(090-225)	(5)
128 -	9:	UPPER SHOULDER BELT LOAD	LBS	401	2025.	LP(090-225)	(5)
129 -	10:	LOWER SHOULDER BELT LOAD	LBS	401	2025.	LP(090-225)	(5)
	11:						
	12:						

FILES: 121 - 129 ON TAPE: GMR-F1 RUN: A-888-2: DM3X-L FILTERED JAN 21, 1976 02:07:59



JAN 21, 1976 / 13:50:17
RUN ID: A-888-2: DM3X-L
8 MS
20 PTS
< 2> 3.E+01
< 3> 6.E+00
< 4> 3.E+00
< 5> 2.E+00
< 6> 2.E+00
< 7> 6.E+01
< 8> 1.E+02
< 9> 9.E+01
<10> 5.E+01
8 MS
20 PTS
FILES: 121-129, TAPE:GMR-F1
401 PTS @ 2024 HZ = 197.5 MS

TAPE: GMR-F1

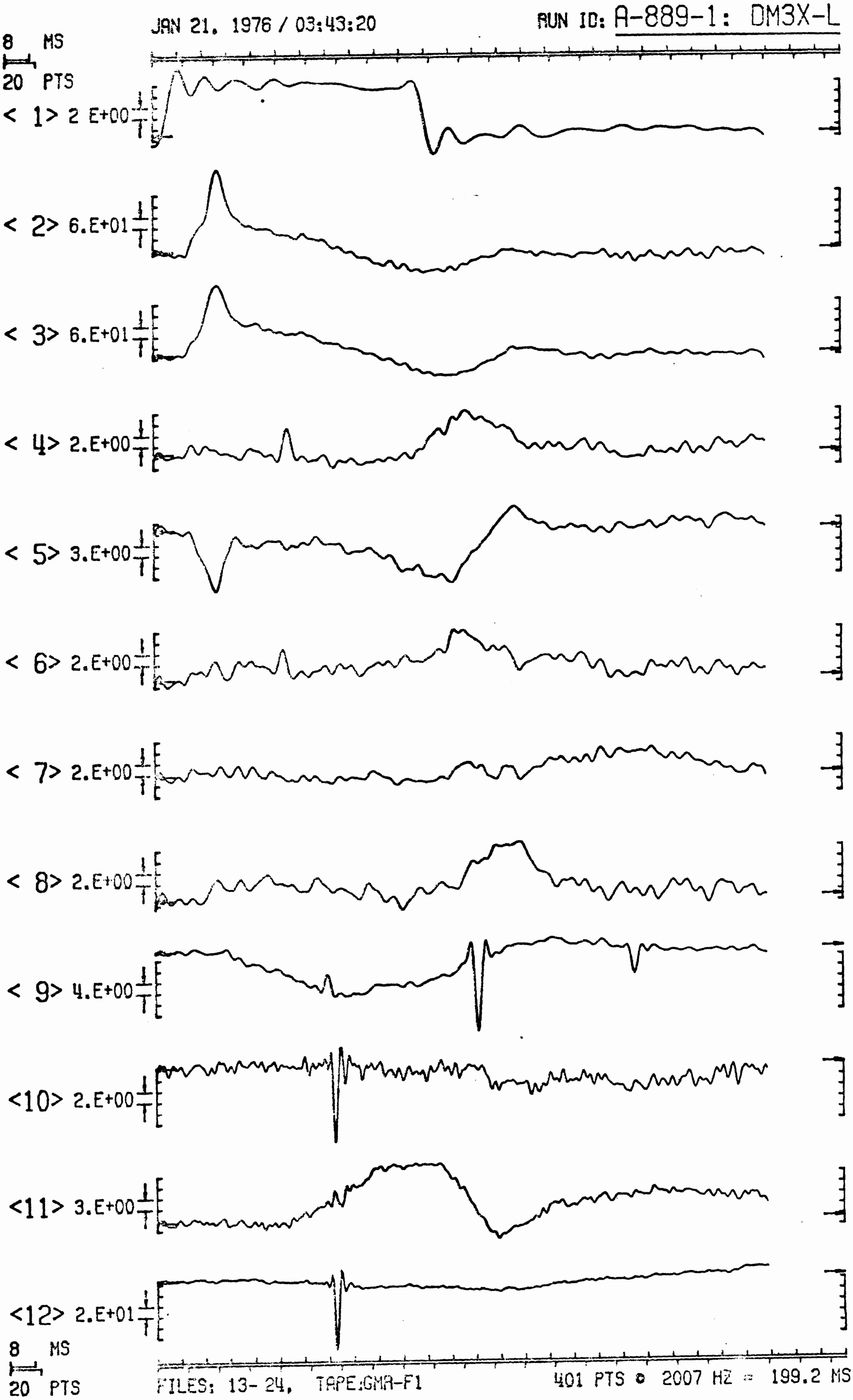
DIGITAL SIGNAL FILTERING
JAN 21, 1976 01:36:32

RUN ID: A-889-1: DM3X-L

PROJECT: WHOLE BODY RESPONSE: DUMMY WITH TRIAXIALS AND BIAXIALS.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
13 -	1:	SLED DECELERATION	G'S	401	2008.	LP(030-090)	(4)
14 -	2:	RIGHT FEMUR LOAD	LBS	401	2008.	LP(090-225)	(5)
15 -	3:	LEFT FEMUR LOAD	LBS	401	2008.	LP(090-225)	(5)
16 -	4:	CHEST TRIAX P-A ACC	G'S	401	2008.	LP(090-225)	(5)
17 -	5:	CHEST TRIAX I-S ACC	G'S	401	2008.	LP(090-225)	(5)
18 -	6:	CHEST TRIAX R-L ACC	G'S	401	2008.	LP(090-225)	(5)
19 -	7:	PELVIS TRIAX I-S ACC	G'S	401	2008.	LP(090-225)	(5)
20 -	8:	PELVIS TRIAX P-A ACC	G'S	401	2008.	LP(090-225)	(5)
21 -	9:	PELVIS TRIAX R-L ACC	G'S	401	2008.	LP(090-225)	(5)
22 -	10:	HEAD TRIAX P-A ACC	G'S	401	2008.	LP(180-350)	(6)
23 -	11:	HEAD TRIAX I-S ACC	G'S	401	2008.	LP(180-350)	(6)
24 -	12:	HEAD TRIAX R-L ACC	G'S	401	2008.	LP(180-350)	(6)

FILES: 13 - 24 ON TAPE: GMR-F1 RUN: A-889-1: DM3X-L FILTERED JAN 21, 1976 01:37:18


JAN 21, 1976 / 03:43:20
RUN ID: A-889-1: DM3X-L
8 MS
20 PTS
< 1> 2 E+00
< 2> 6.E+01
< 3> 6.E+01
< 4> 2.E+00
< 5> 3.E+00
< 6> 2.E+00
< 7> 2.E+00
< 8> 2.E+00
< 9> 4.E+00
<10> 2.E+00
<11> 3.E+00
<12> 2.E+01
8 MS
20 PTS
FILES: 13- 24, TAPE:GMA-F1
401 PTS @ 2007 HZ = 199.2 MS

TAPE: GMR-F1

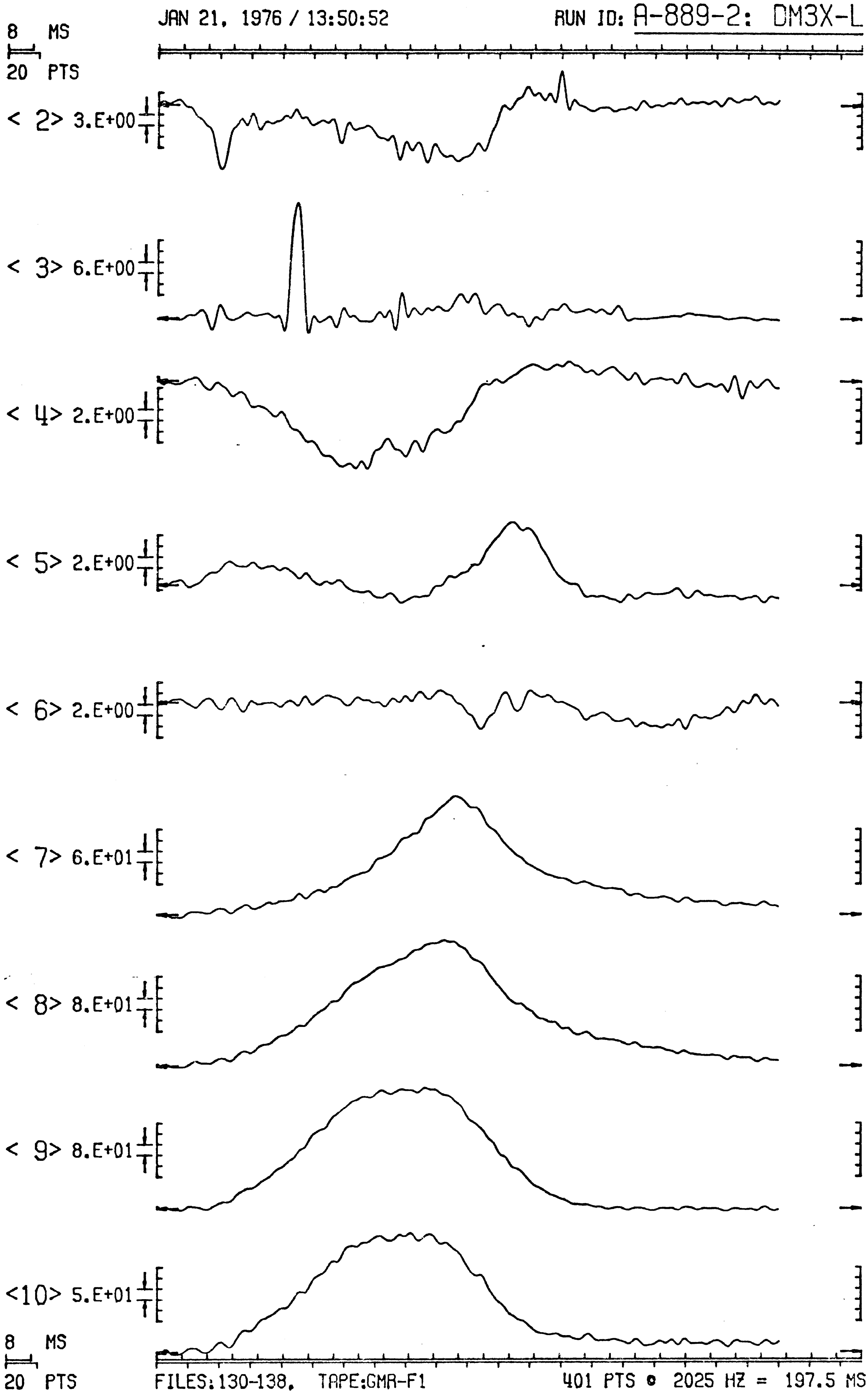
DIGITAL SIGNAL FILTERING
JAN 21, 1976 02:09:09

RUN ID: A-889-2: DM3X-L

PROJECT: WHOLE BODY RESPONSE.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
	1:						
130 -	2:	PELVIS EXT A-P ACC	G'S	401	2025.	LP(090-225)	(5)
131 -	3:	PELVIS EXT S-I ACC	G'S	401	2025.	LP(090-225)	(5)
132 -	4:	THORAX EXT A-P ACC	G'S	401	2025.	LP(090-225)	(5)
133 -	5:	THORAX EXT S-I ACC	G'S	401	2025.	LP(090-225)	(5)
134 -	6:	THORAX EXT L-R ACC	G'S	401	2025.	LP(090-225)	(5)
135 -	7:	RIGHT LAP BELT LOAD	LBS	401	2025.	LP(090-225)	(5)
136 -	8:	LEFT LAP BELT LOAD	LBS	401	2025.	LP(090-225)	(5)
137 -	9:	UPPER SHOULDER BELT LOAD	LBS	401	2025.	LP(090-225)	(5)
138 -	10:	LOWER SHOULDER BELT LOAD	LBS	401	2025.	LP(090-225)	(5)
	11:						
	12:						

FILES: 130 - 138 ON TAPE: GMR-F1 RUN: A-889-2: DM3X-L FILTERED JAN 21, 1976 02:09:46


JAN 21, 1976 / 13:50:52
RUN ID: A-889-2: DM3X-L
8 MS
20 PTS
< 2> 3.E+00
< 3> 6.E+00
< 4> 2.E+00
< 5> 2.E+00
< 6> 2.E+00
< 7> 6.E+01
< 8> 8.E+01
< 9> 8.E+01
<10> 5.E+01
8 MS
20 PTS
FILES: 130-138, TAPE:GMR-F1
401 PTS @ 2025 HZ = 197.5 MS

TAPE: GMR-F1

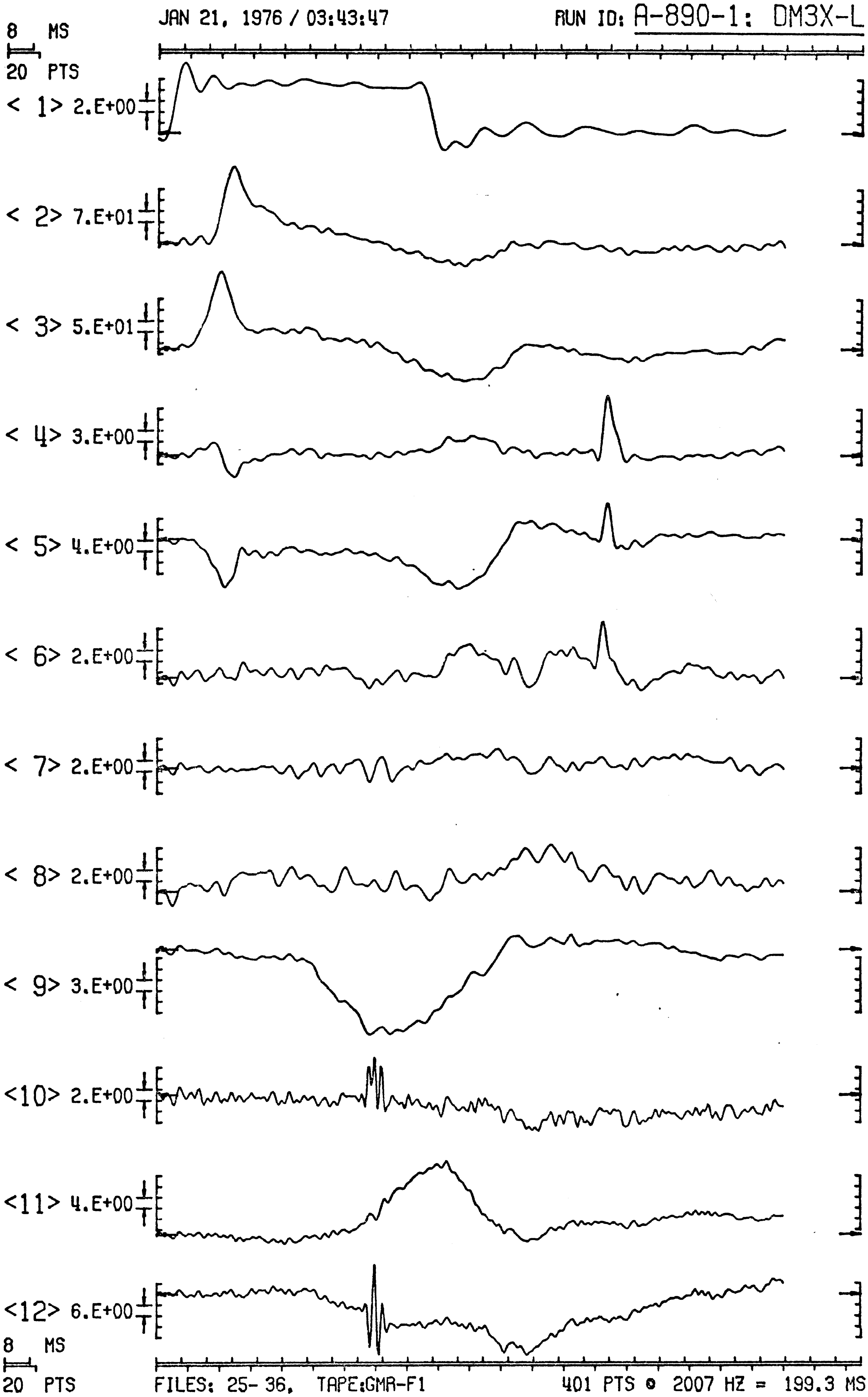
DIGITAL SIGNAL FILTERING
JAN 21, 1976 01:38:54

RUN ID: A-890-1: DM3X-L

PROJECT: WHOLE BODY RESPONSE: DUMMY WITH TRIAXIALS AND BIAXIALS.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
25 -	1:	SLED DECELERATION	G'S	401	2007.	LP(030-030)	(4)
26 -	2:	RIGHT FEMUR LOAD	LBS	401	2007.	LP(090-225)	(5)
27 -	3:	LEFT FEMUR LOAD	LBS	401	2007.	LP(090-225)	(5)
28 -	4:	CHEST TRIAX P-A ACC	G'S	401	2007.	LP(090-225)	(5)
29 -	5:	CHEST TRIAX I-S ACC	G'S	401	2007.	LP(090-225)	(5)
30 -	6:	CHEST TRIAX R-L ACC	G'S	401	2007.	LP(090-225)	(5)
31 -	7:	PELVIS TRIAX I-S ACC	G'S	401	2007.	LP(090-225)	(5)
32 -	8:	PELVIS TRIAX P-A ACC	G'S	401	2007.	LP(090-225)	(5)
33 -	9:	PELVIS TRIAX R-L ACC	G'S	401	2007.	LP(090-225)	(5)
34 -	10:	HEAD TRIAX P-A ACC	G'S	401	2007.	LP(180-360)	(6)
35 -	11:	HEAD TRIAX I-S ACC	G'S	401	2007.	LP(180-360)	(6)
36 -	12:	HEAD TRIAX R-L ACC	G'S	401	2007.	LP(180-360)	(6)

FILES: 25 - 36 ON TAPE: GMR-F1 RUN: A-890-1: DM3X-L FILTERED JAN 21, 1976 01:39:37



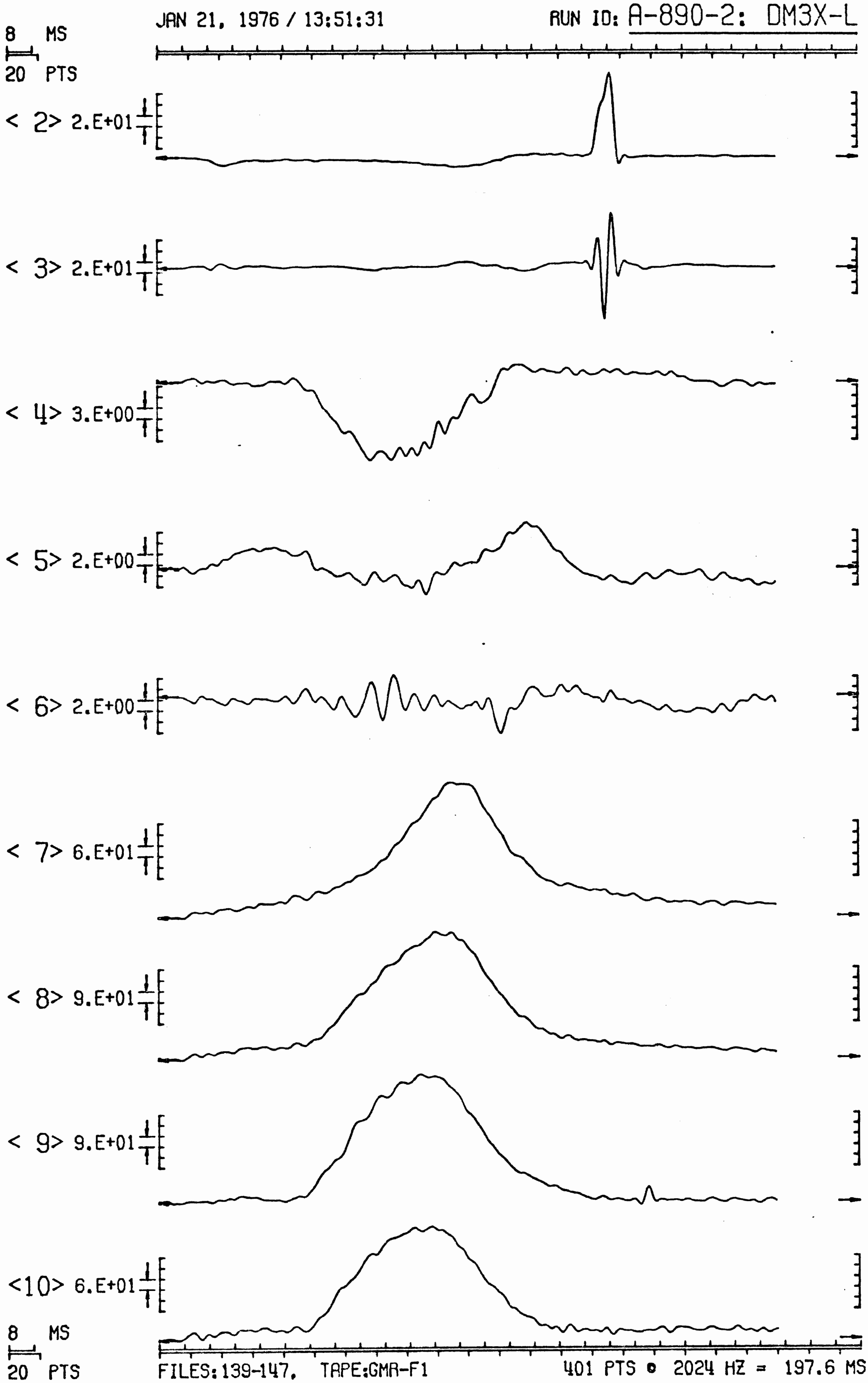
JAN 21, 1976 / 03:43:47
RUN ID: A-890-1: DM3X-L
8 MS
20 PTS
< 1> 2.E+00
< 2> 7.E+01
< 3> 5.E+01
< 4> 3.E+00
< 5> 4.E+00
< 6> 2.E+00
< 7> 2.E+00
< 8> 2.E+00
< 9> 3.E+00
<10> 2.E+00
<11> 4.E+00
<12> 6.E+00
8 MS
20 PTS
FILES: 25- 36, TAPE:GMA-F1
401 PTS @ 2007 HZ = 199.3 MS

TAPE: GMR-F1 | DIGITAL SIGNAL FILTERING JAN 21, 1976 02:10:58 | RUN ID: A-890-2: DM3X-L

PROJECT: WHOLE BODY RESPONSE.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
	1:						
139 -	2:	PELVIS EXT A-P ACC	G'S	401	2024.	LP(090-225)	(5)
140 -	3:	PELVIS EXT S-I ACC	G'S	401	2024.	LP(090-225)	(5)
141 -	4:	THORAX EXT A-P ACC	G'S	401	2024.	LP(090-225)	(5)
142 -	5:	THORAX EXT S-I ACC	G'S	401	2024.	LP(090-225)	(5)
143 -	6:	THORAX EXT L-R ACC	G'S	401	2024.	LP(090-225)	(5)
144 -	7:	RIGHT LAP BELT LOAD	LBS	401	2024.	LP(090-225)	(5)
145 -	8:	LEFT LAP BELT LOAD	LBS	401	2024.	LP(090-225)	(5)
146 -	9:	UPPER SHOULDER BELT LOAD	LBS	401	2024.	LP(090-225)	(5)
147 -	10:	LOWER SHOULDER BELT LOAD	LBS	401	2024.	LP(090-225)	(5)
	11:						
	12:						

FILES: 139 - 147 ON TAPE: GMR-F1 RUN: A-890-2: DM3X-L FILTERED JAN 21, 1976 02:11:28


JAN 21, 1976 / 13:51:31
RUN ID: A-890-2: DM3X-L
8 MS
20 PTS
< 2> 2.E+01
< 3> 2.E+01
< 4> 3.E+00
< 5> 2.E+00
< 6> 2.E+00
< 7> 6.E+01
< 8> 9.E+01
< 9> 9.E+01
<10> 6.E+01
8 MS
20 PTS
FILES: 139-147, TAPE:GMR-F1
401 PTS @ 2024 HZ = 197.6 MS

DIGITAL SIGNAL FILTERING
JAN 21, 1976 01:51:43

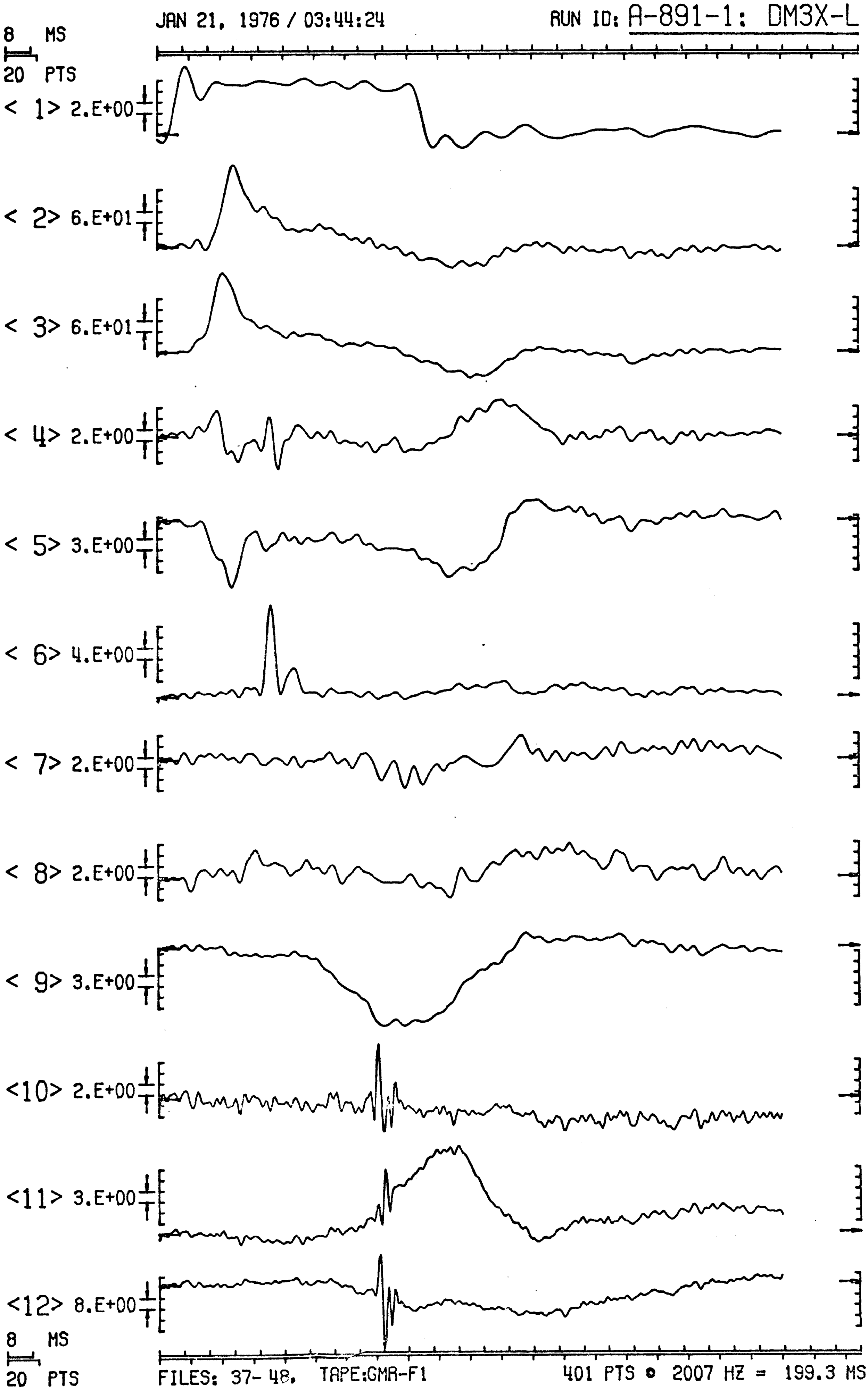
TAPE: GMR-F1

RUN ID: A-891-1: DM3X-L

PROJECT: WHOLE BODY RESPONSE: DUMMY WITH TRIAXIALS AND BIAXIALS.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
37 -	1:	SLED DECELERATION	G'S	401	2007.	LP(030-090)	(4)
38 -	2:	RIGHT FEMUR LOAD	LBS	401	2007.	LP(090-225)	(5)
39 -	3:	LEFT FEMUR LOAD	LBS	401	2007.	LP(090-225)	(5)
40 -	4:	CHEST TRIAX P-A ACC	G'S	401	2007.	LP(090-225)	(5)
41 -	5:	CHEST TRIAX I-S ACC	G'S	401	2007.	LP(090-225)	(5)
42 -	6:	CHEST TRIAX R-L ACC	G'S	401	2007.	LP(090-225)	(5)
43 -	7:	PELVIS TRIAX I-S ACC	G'S	401	2007.	LP(090-225)	(5)
44 -	8:	PELVIS TRIAX P-A ACC	G'S	401	2007.	LP(090-225)	(5)
45 -	9:	PELVIS TRIAX R-L ACC	G'S	401	2007.	LP(090-225)	(5)
46 -	10:	HEAD TRIAX P-A ACC	G'S	401	2007.	LP(180-360)	(6)
47 -	11:	HEAD TRIAX I-S ACC	G'S	401	2007.	LP(180-360)	(6)
48 -	12:	HEAD TRIAX R-L ACC	G'S	401	2007.	LP(180-360)	(6)

FILES: 37 - 48 ON TAPE: GMR-F1 RUN: A-891-1: DM3X-L FILTERED JAN 21, 1976 01:52:29


JAN 21, 1976 / 03:44:24
RUN ID: A-891-1: DM3X-L
8 MS
20 PTS
< 1> 2.E+00
< 2> 6.E+01
< 3> 6.E+01
< 4> 2.E+00
< 5> 3.E+00
< 6> 4.E+00
< 7> 2.E+00
< 8> 2.E+00
< 9> 3.E+00
<10> 2.E+00
<11> 3.E+00
<12> 8.E+00
8 MS
20 PTS
FILES: 37- 48, TAPE:GMR-F1
401 PTS @ 2007 HZ = 199.3 MS

TAPE: GMR-F1

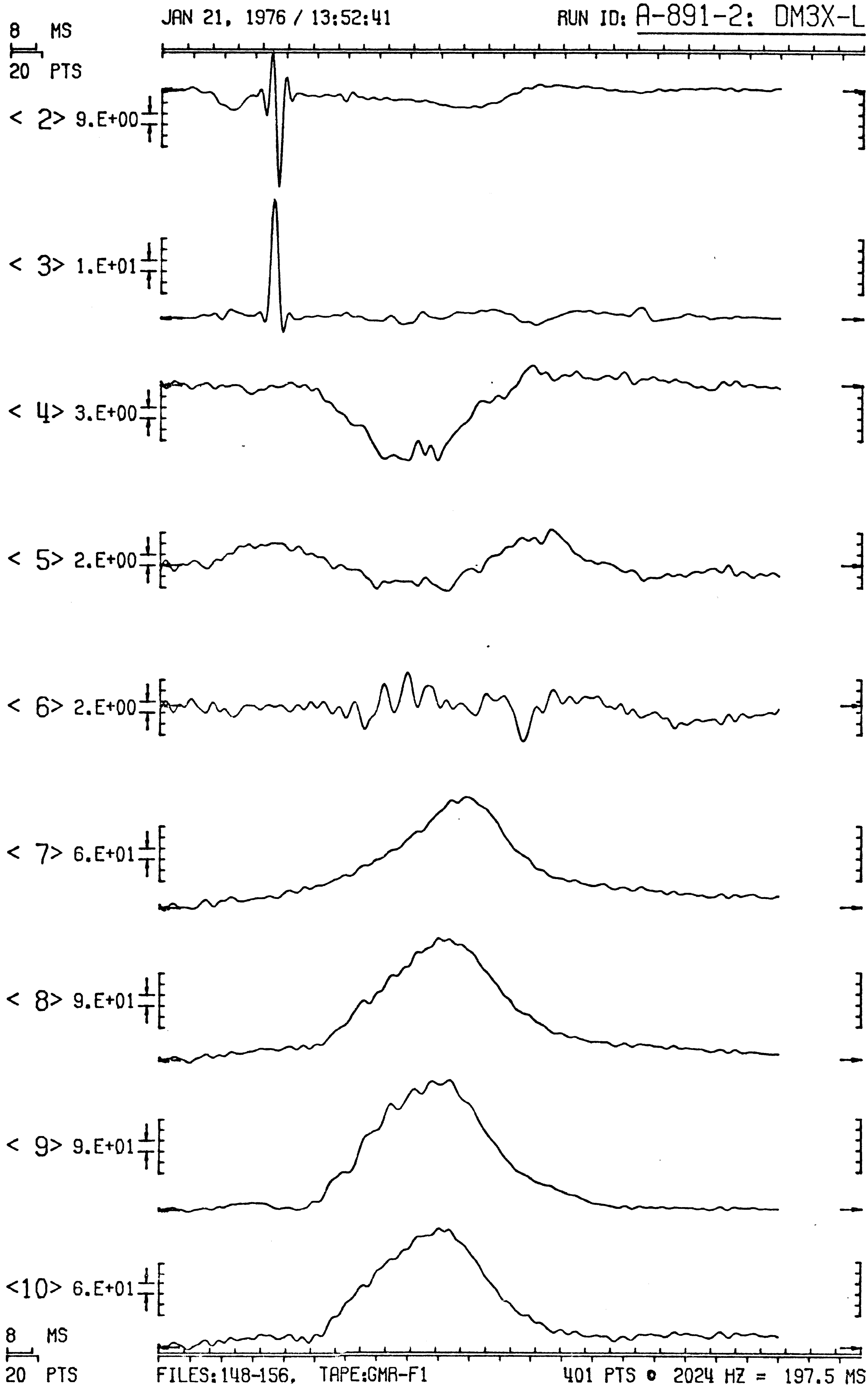
DIGITAL SIGNAL FILTERING
JAN 21, 1976 02:14:19

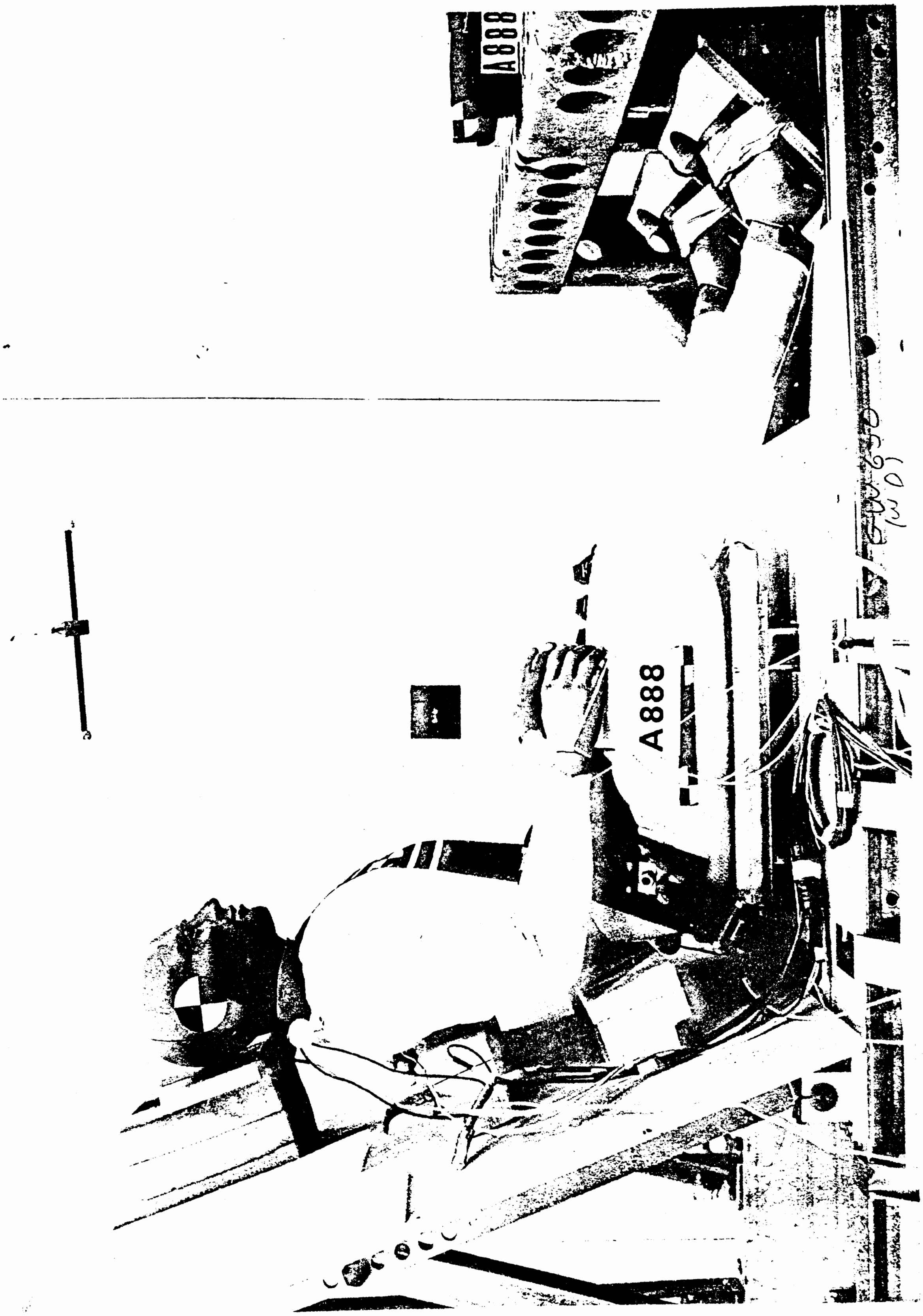
RUN ID: A-891-2: DM3X-L

PROJECT: WHOLE BODY RESPONSE.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
	1:						
148 -	2:	PELVIS EXT A-P ACC	G'S	401	2025.	LP(090-225)	(5)
149 -	3:	PELVIS EXT S-I ACC	G'S	401	2025.	LP(090-225)	(5)
150 -	4:	THORAX EXT A-P ACC	G'S	401	2025.	LP(090-225)	(5)
151 -	5:	THORAX EXT S-I ACC	G'S	401	2025.	LP(090-225)	(5)
152 -	6:	THORAX EXT L-R ACC	G'S	401	2025.	LP(090-225)	(5)
153 -	7:	RIGHT LAP BELT LOAD	LBS	401	2025.	LP(090-225)	(5)
154 -	8:	LEFT LAP BELT LOAD	LBS	401	2025.	LP(090-225)	(5)
155 -	9:	UPPER SHOULDER BELT LOAD	LBS	401	2025.	LP(090-225)	(5)
156 -	10:	LOWER SHOULDER BELT LOAD	LBS	401	2025.	LP(090-225)	(5)
	11:						
	12:						

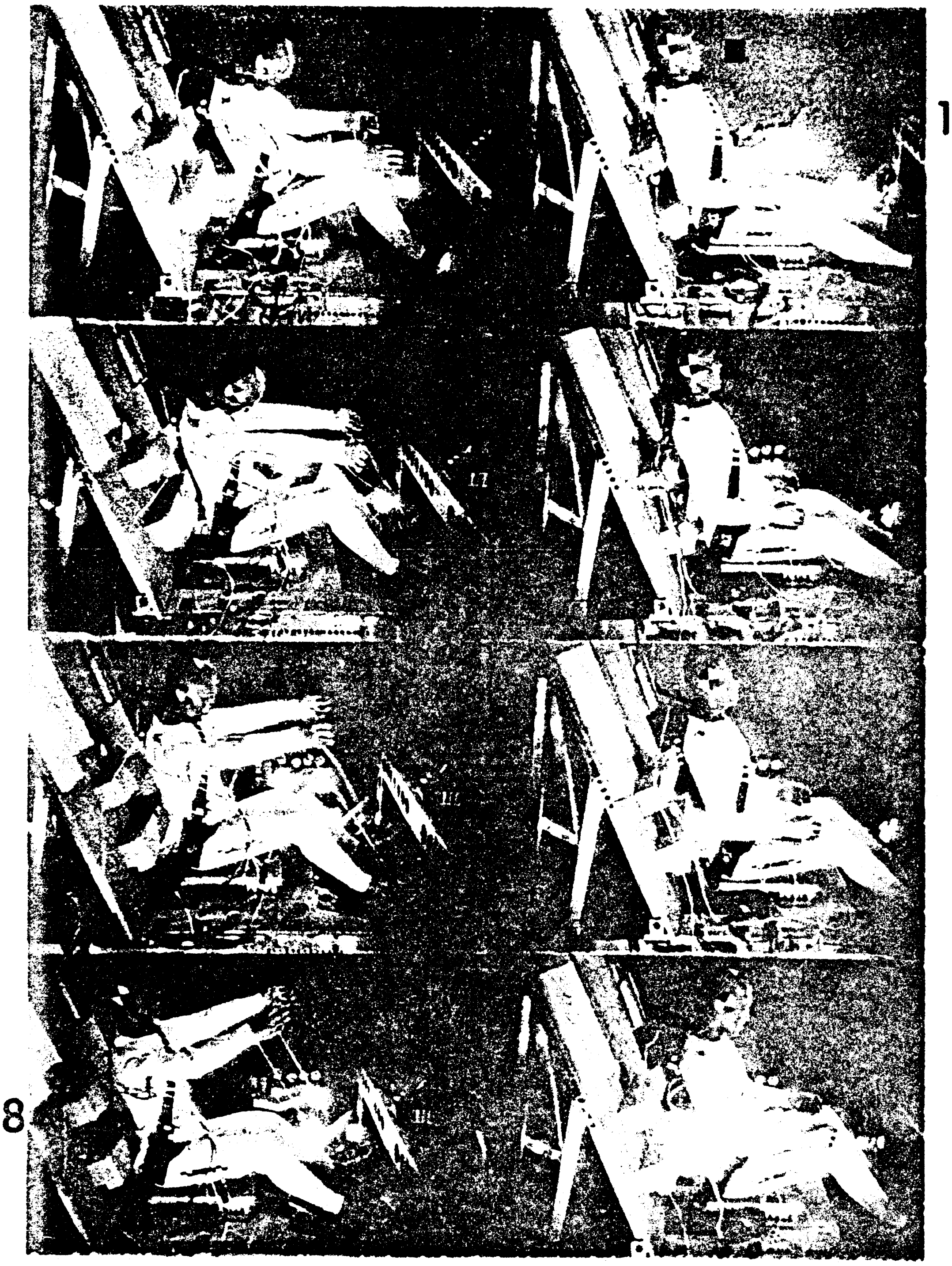
FILES: 148 - 156 ON TAPE: GMR-F1 RUN: A-891-2: DM3X-L FILTERED JAN 21, 1976 02:14:48


JAN 21, 1976 / 13:52:41
RUN ID: A-891-2: DM3X-L
8 MS
20 PTS
< 2> 9.E+00
< 3> 1.E+01
< 4> 3.E+00
< 5> 2.E+00
< 6> 2.E+00
< 7> 6.E+01
< 8> 9.E+01
< 9> 9.E+01
<10> 6.E+01
8 MS
20 PTS
FILES:148-156, TAPE:GMR-F1
401 PTS @ 2024 HZ = 197.5 MS

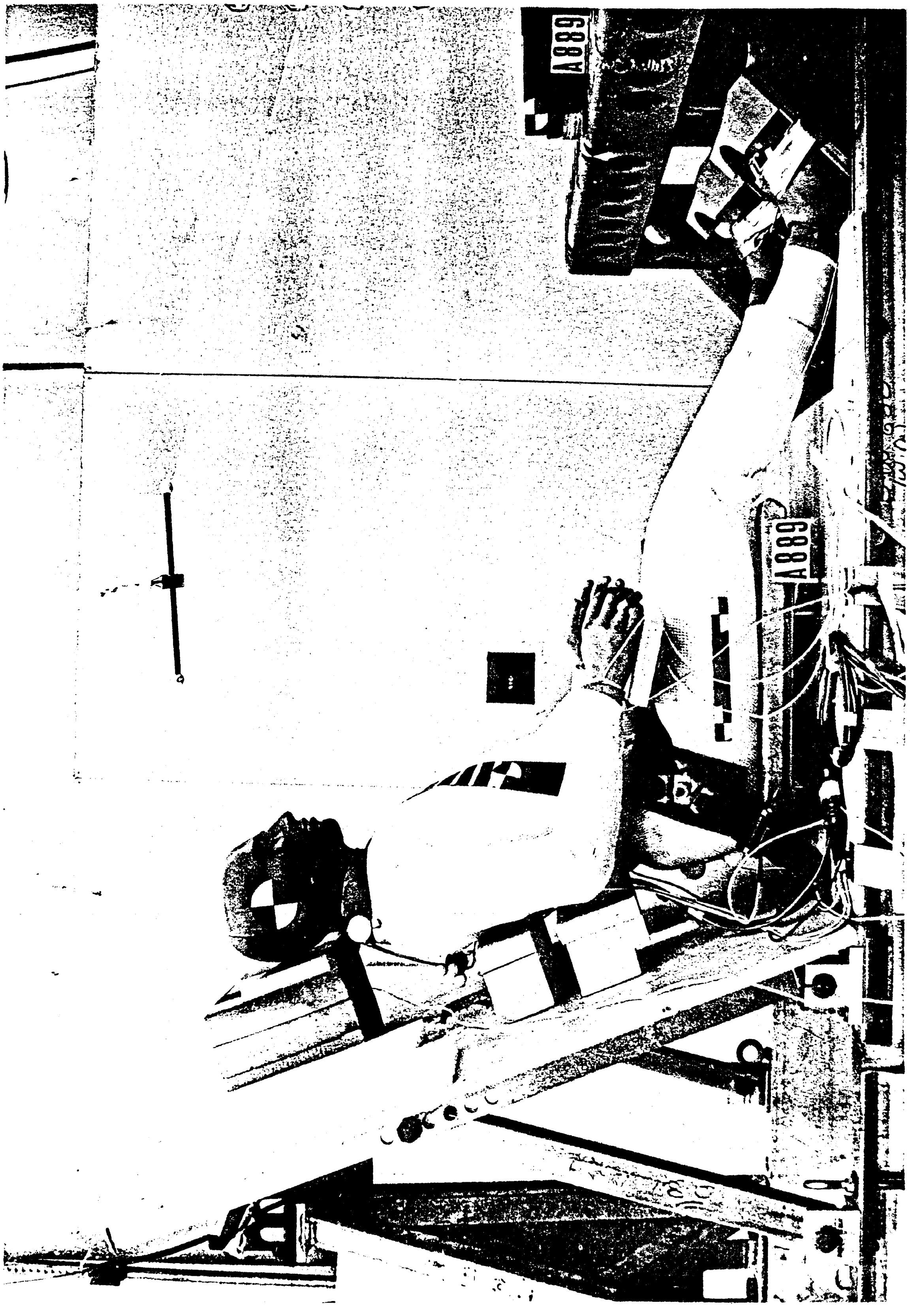


SETUP PHOTOGRAPH: TEST A-888

SETUP PHOTOGRAPH: TEST A-888



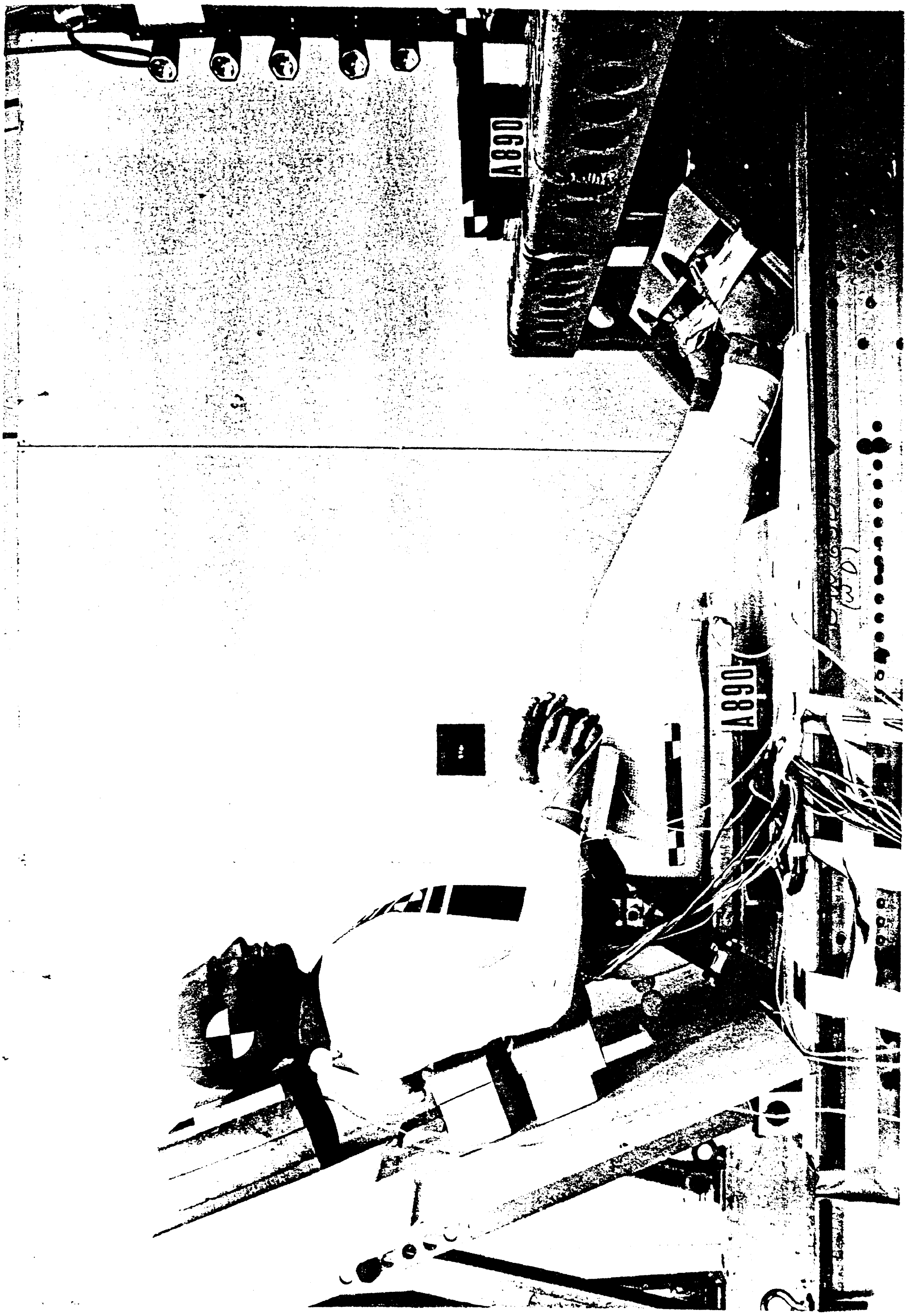
GRAPHCHECK PHOTOGRAPH: TEST A-888



SETUP PHOTOGRAPH: TEST A-889

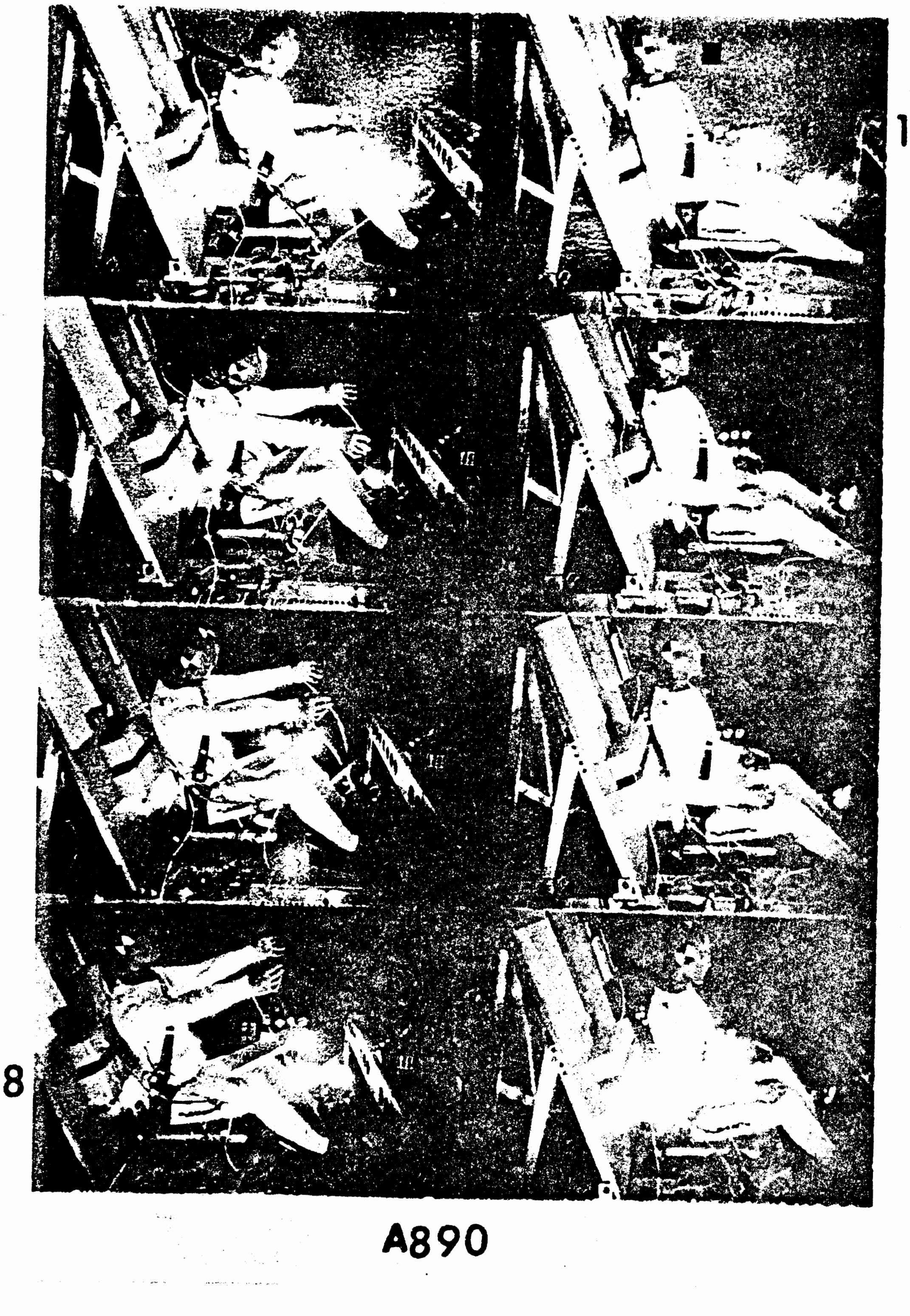
SETUP PHOTOGRAPH: TEST A-889

GRAPHCHECK PHOTOGRAPH: TEST A-889

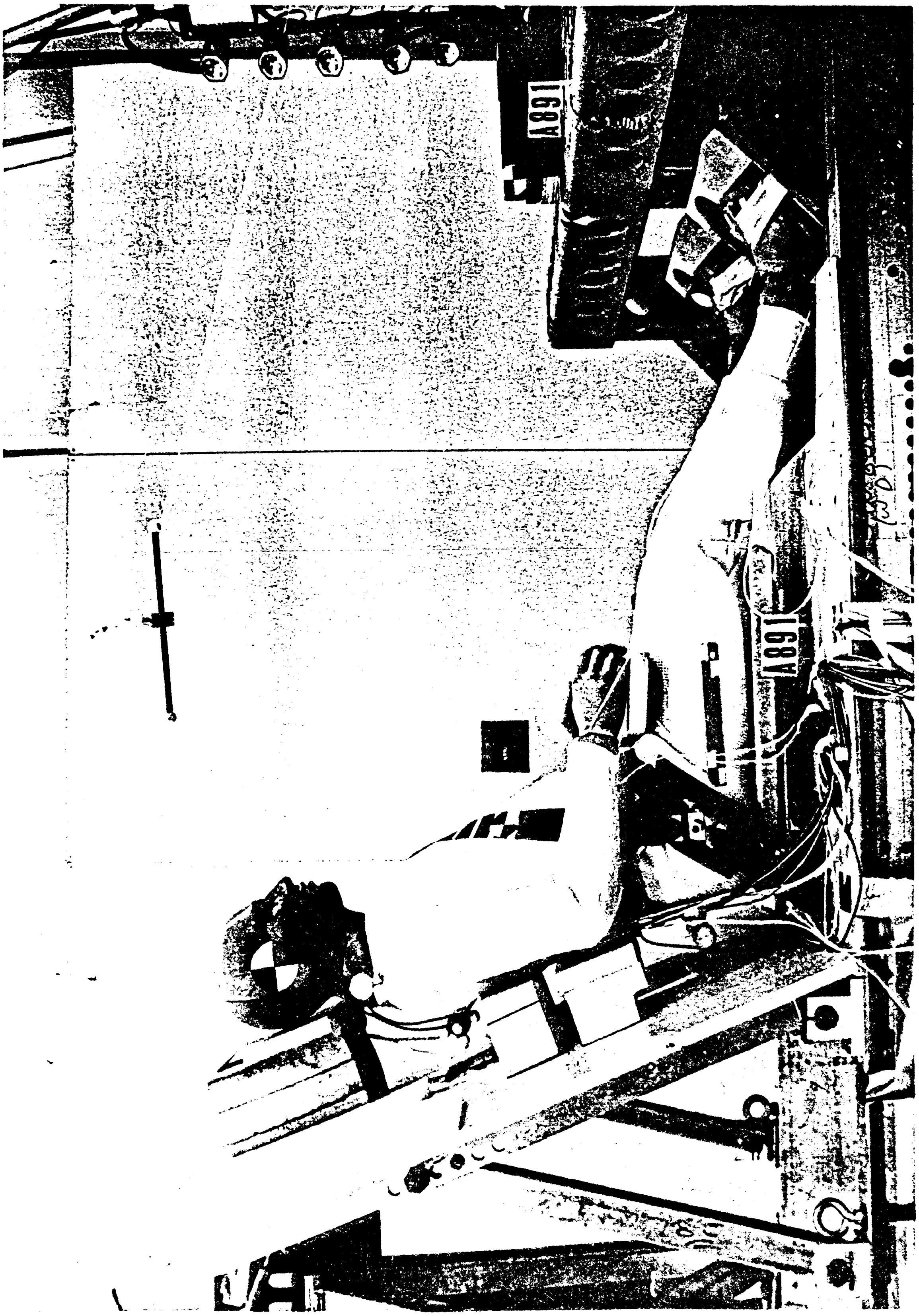


SETUP PHOTOGRAPH: TEST A-890

SETUP PHOTOGRAPH: TEST A-890



GRAPHCHECK PHOTOGRAPH: TEST A-890



SETUP PHOTOGRAPH: TEST A-891

SETUP PHOTOGRAPH: TEST A-891

GRAPHCHECK PHOTOGRAPH: TEST A-891

WHOLE BODY RESPONSE

CERTIFIED DUMMY TEST

Intermediate Severity Impact

Type I Instrumentation

Frontal Impact

Three Point Belt Restraint

IMPACT PARAMETERS

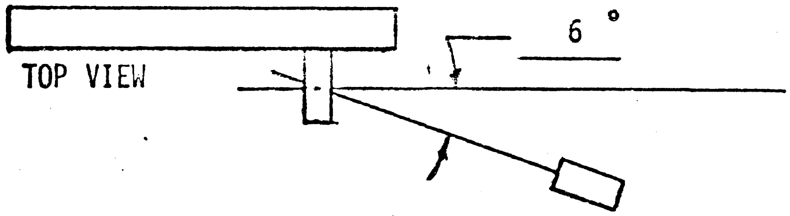
TEST NO.	IMPACT VELOCITY (MPH)	IMPACT DECELERATION (G's)
A-892	22.7	10.0
A-893	22.3	10.0
A-894	22.4	10.4

WBR# Certified Dummy

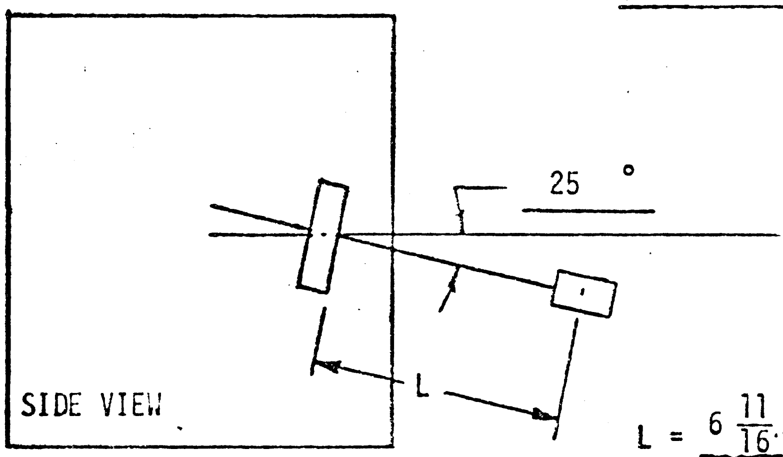
Test No. A-892

WHOLE BODY RESPONSE

BELT ANCHOR ORIENTATIONS

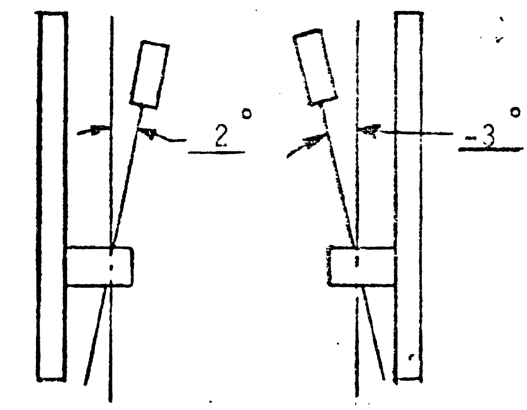


SHOULDER BELT



L = 6 $\frac{11}{16}$ in.

LAP BELT

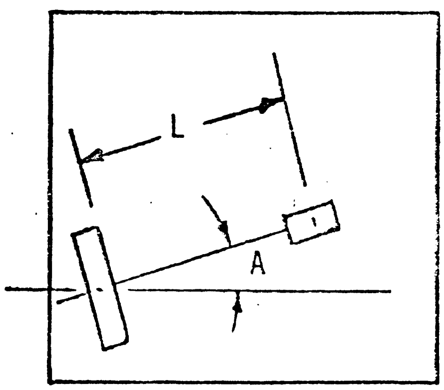


LEFT SIDE

RIGHT SIDE

TOP VIEW

(Sketch indicates Positive Angle directions)



SIDE VIEW

L_{LEFT} = 5 5/8 in.

L_{RIGHT} = 5 3/4 in.

A_{LEFT} = 52 °

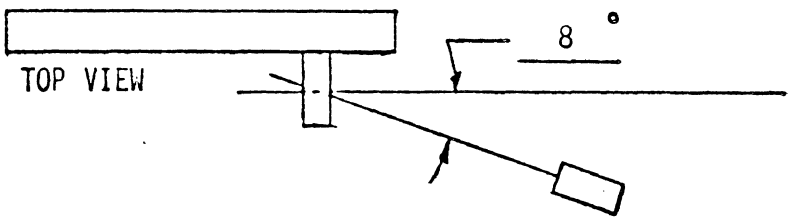
A_{RIGHT} = 60 °

WBR# Certified Dummy

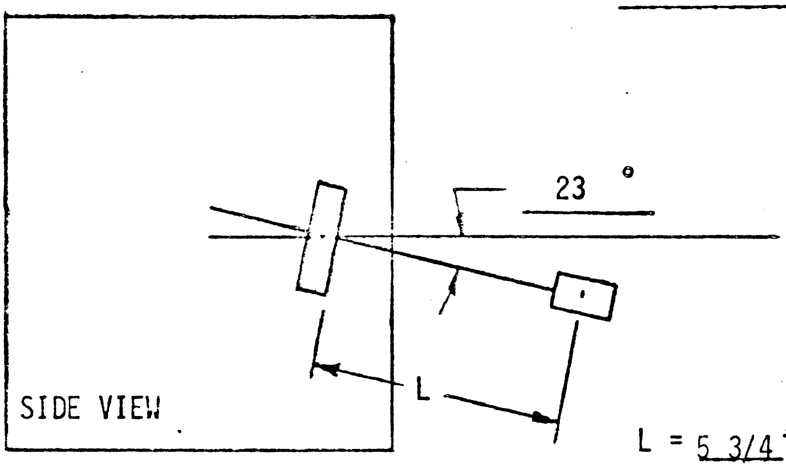
Test No. A-893

WHOLE BODY RESPONSE

BELT ANCHOR ORIENTATIONS

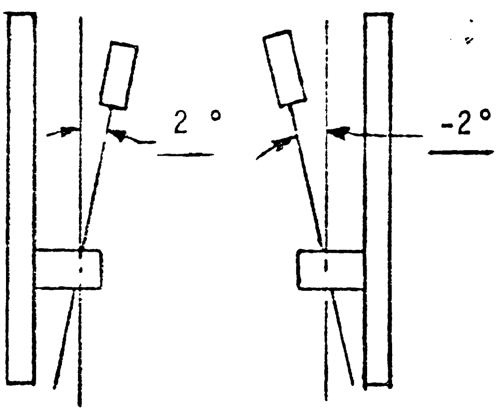


SHOULDER BELT



L = 5 3/4 in.

LAP BELT

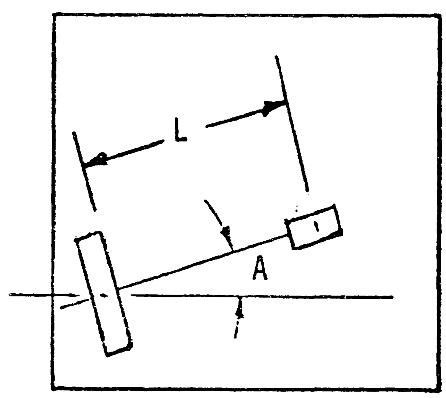


LEFT SIDE

RIGHT SIDE

TOP VIEW

(Sketch indicates Positive Angle directions)



SIDE VIEW

L_{LEFT} = 4 7/8 in.

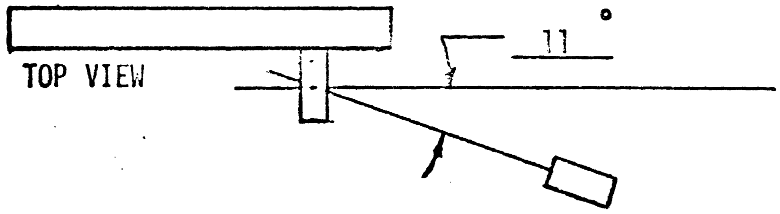
L_{RIGHT} = 6 5/8 in.

A_{LEFT} = 53 °

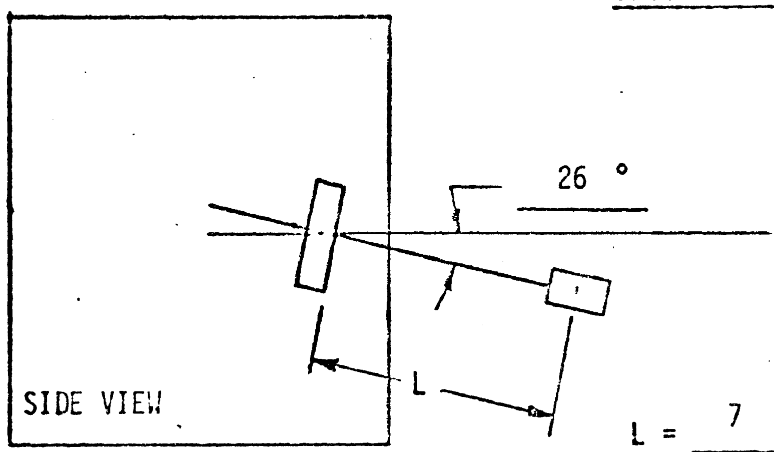
A_{RIGHT} = 59 °

WHOLE BODY RESPONSE

BELT ANCHOR ORIENTATIONS

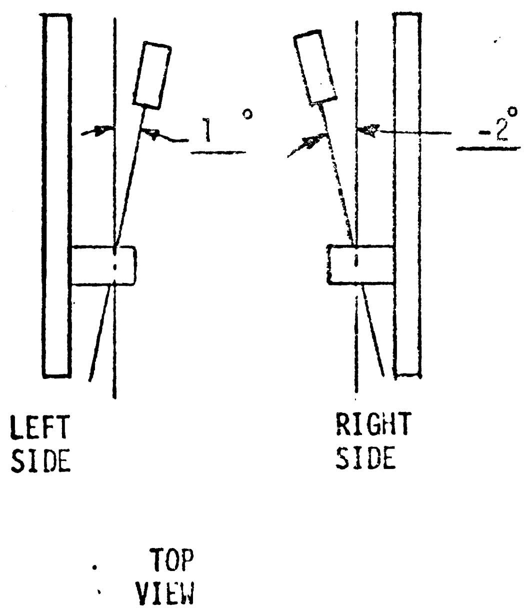


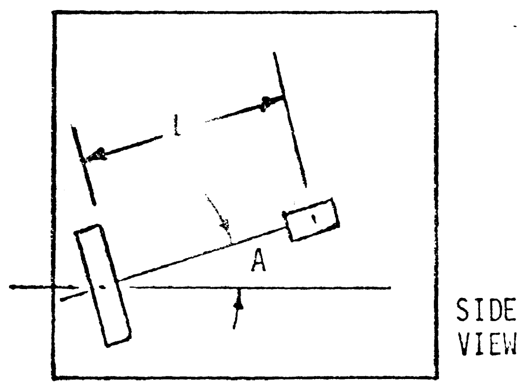
SHOULDER BELT



L = 7 in.

LAP BELT





L_{LEFT} = 4 3/4 in.

L_{RIGHT} = 6 1/16 in.

A_{LEFT} = 54 °

A_{RIGHT} = 56 °

(Sketch indicates Positive Angle directions)

WHOLE BODY RESPONSE WBR# Certified Dummy

BELT LENGTH DATA

TEST A- 892

Belt Position	Pre-Impact Length (in)	Post-Impact Length (in)	Belt Stretch (in)	Post-Impact Length with Load Cells
Rt. Lap	12	12	0	11 1/4
Lt. Lap	32 1/2	32 1/2	0	31 3/4
Shoulder	42	42 1/8	1/8	40 1/2

Test A- 893

Belt Position	Pre-Impact Length (in)	Post-Impact Length (in)	Belt Stretch (in)	Post-Impact Length with Load Cells
Rt. Lap	12	12	0	11 3/8
Lt. Lap	32 1/2	32 3/4	1/4	31 7/8
Shoulder	42	42 1/8	1/8	40 1/2

WHOLE BODY RESPONSE WBR# Certified Dummy

BELT LENGTH DATA

TEST A- 894

Belt Position	Pre-Impact Length (in)	Post-Impact Length (in)	Belt Stretch (in)	Post-Impact Length with Load Cells
Rt. Lap	12	12	0	11 3/8
Lt. Lap	32 1/2	32 7/8	3/8	32 1/8
Shoulder	42	42 1/4	1/4	40 3/4

Test A-

Belt Position	Pre-Impact Length (in)	Post-Impact Length (in)	Belt Stretch (in)	Post-Impact Length with Load Cells
Rt. Lap				
Lt. Lap				
Shoulder				

TAPE: GMR-F1

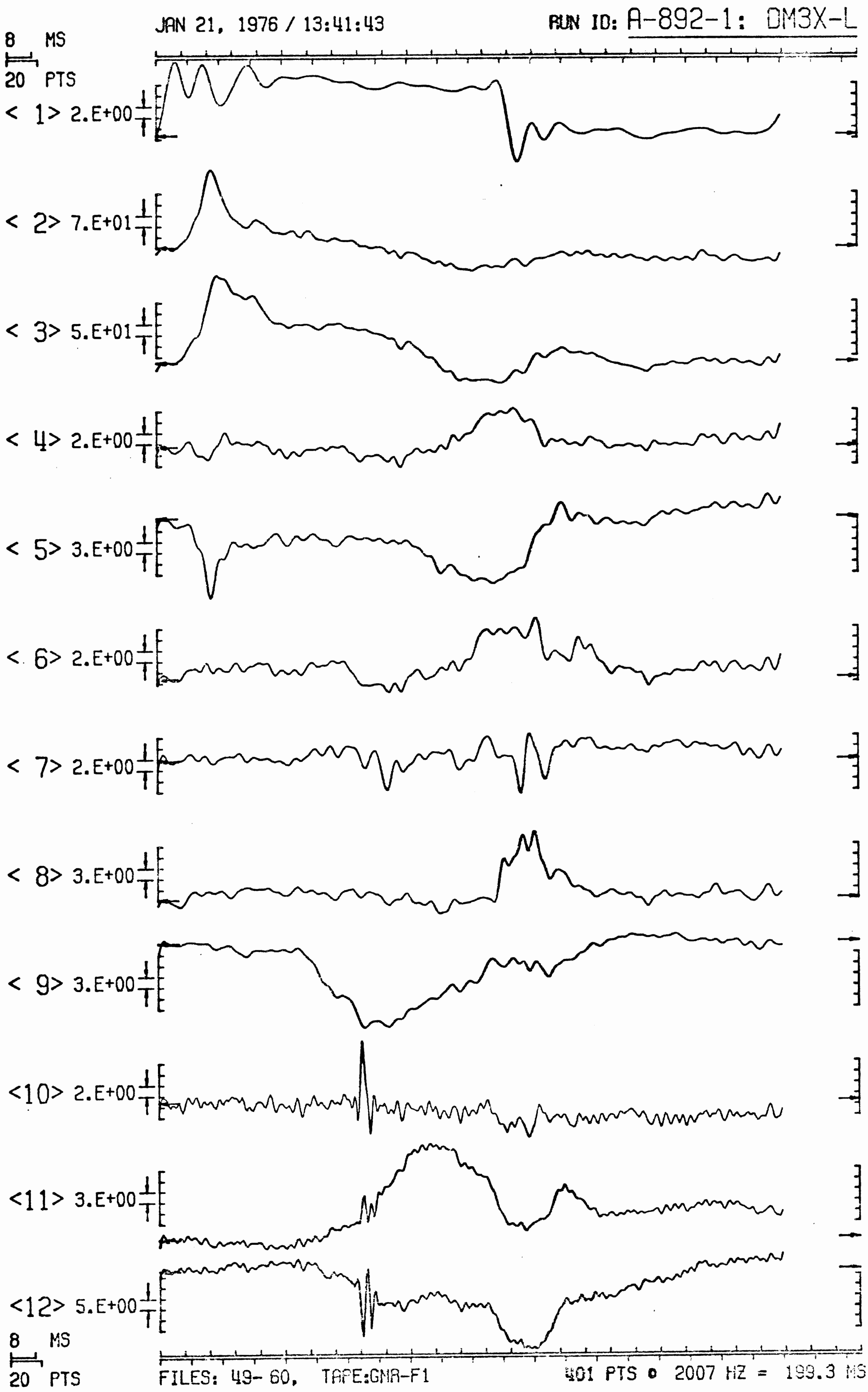
DIGITAL SIGNAL FILTERING
JAN 21, 1976 01:53:57

RUN ID: A-892-1: DM3X-L

PROJECT: WHOLE BODY RESPONSE: DUMMY WITH TRIAXIALS AND BIAXIALS.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
49 -	1:	SLED DECELERATION	G'S	401	2007.	LP(030-090)	(4)
50 -	2:	RIGHT FEMUR LOAD	LBS	401	2007.	LP(090-225)	(5)
51 -	3:	LEFT FEMUR LOAD	LBS	401	2007.	LP(090-225)	(5)
52 -	4:	CHEST TRIAX P-A ACC	G'S	401	2007.	LP(090-225)	(5)
53 -	5:	CHEST TRIAX I-S ACC	G'S	401	2007.	LP(090-225)	(5)
54 -	6:	CHEST TRIAX R-L ACC	G'S	401	2007.	LP(090-225)	(5)
55 -	7:	PELVIS TRIAX I-S ACC	G'S	401	2007.	LP(090-225)	(5)
56 -	8:	PELVIS TRIAX P-A ACC	G'S	401	2007.	LP(090-225)	(5)
57 -	9:	PELVIS TRIAX R-L ACC	G'S	401	2007.	LP(090-225)	(5)
58 -	10:	HEAD TRIAX P-A ACC	G'S	401	2007.	LP(180-360)	(6)
59 -	11:	HEAD TRIAX I-S ACC	G'S	401	2007.	LP(180-360)	(6)
60 -	12:	HEAD TRIAX R-L ACC	G'S	401	2007.	LP(180-360)	(6)

FILES: 49 - 60 ON TAPE: GMR-F1 RUN: A-892-1: DM3X-L FILTERED JAN 21, 1976 01:54:46


JAN 21, 1976 / 13:41:43
RUN ID: A-892-1: DM3X-L
8 MS
20 PTS
< 1> 2.E+00
< 2> 7.E+01
< 3> 5.E+01
< 4> 2.E+00
< 5> 3.E+00
< 6> 2.E+00
< 7> 2.E+00
< 8> 3.E+00
< 9> 3.E+00
<10> 2.E+00
<11> 3.E+00
<12> 5.E+00
8 MS
20 PTS
FILES: 49- 60, TAPE:GNA-F1
401 PTS @ 2007 HZ = 199.3 MS

TAPE: GMR-F1 | DIGITAL SIGNAL FILTERING JAN 21, 1976 02:16:02 | RUN ID: A-892-2: DM3X-M

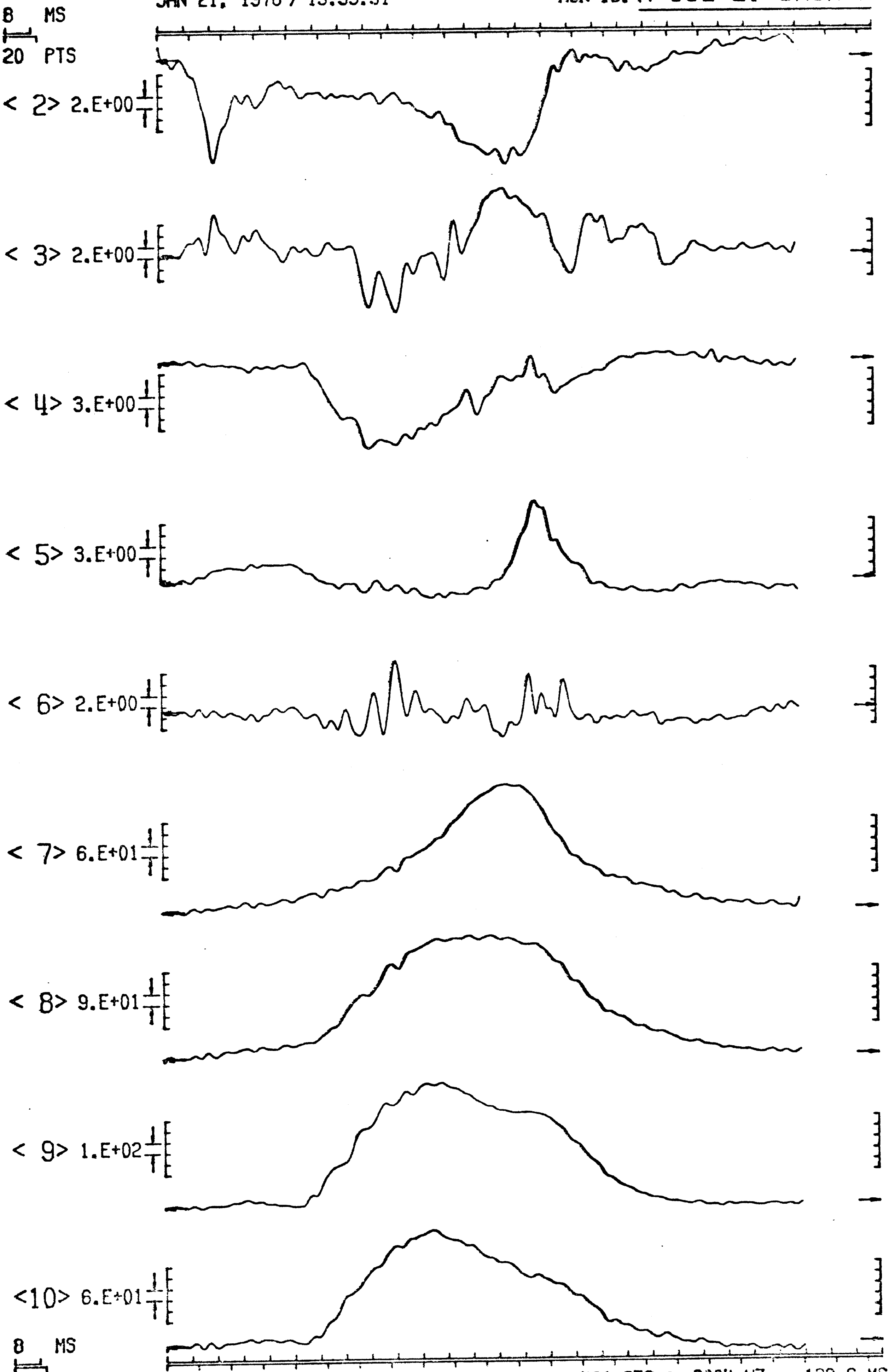
PROJECT: WHOLE BODY RESPONSE.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
	1:						
157 -	2:	PELVIS EXT A-P ACC	G'S	401	2004.	LP(090-225)	(5)
158 -	3:	PELVIS EXT S-I ACC	G'S	401	2004.	LP(090-225)	(5)
159 -	4:	THORAX EXT A-P ACC	G'S	401	2004.	LP(090-225)	(5)
160 -	5:	THORAX EXT S-I ACC	G'S	401	2004.	LP(090-225)	(5)
161 -	6:	THORAX EXT L-R ACC	G'S	401	2004.	LP(090-225)	(5)
162 -	7:	RIGHT LAP BELT LOAD	LBS	401	2004.	LP(090-225)	(5)
163 -	8:	LEFT LAP BELT LOAD	LBS	401	2004.	LP(090-225)	(5)
164 -	9:	UPPER SHOULDER BELT LOAD	LBS	401	2004.	LP(090-225)	(5)
165 -	10:	LOWER SHOULDER BELT LOAD	LBS	401	2004.	LP(090-225)	(5)
	11:						
	12:						

FILES: 157 - 165 ON TAPE: GMR-F1 RUN: A-892-2: DM3X-M FILTERED JAN 21, 1976 02:16:32

JAN 21, 1976 / 13:53:51

RUN ID: A-892-2: DM3X-M



FILES:157-165, TAPE:GMA-F1

401 PTS @ 2004 HZ = 199.6 MS

TAPE: GMR-F1

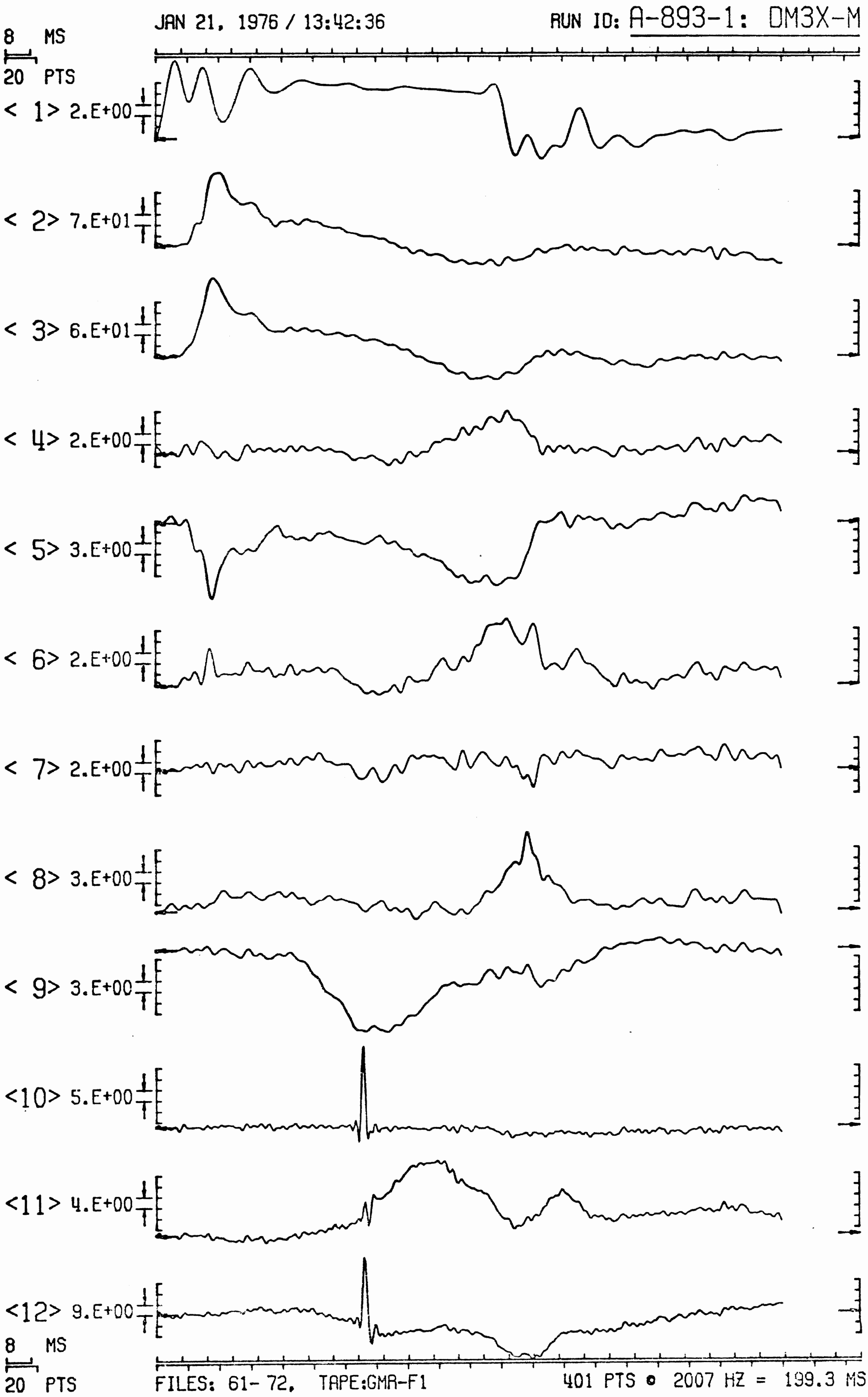
DIGITAL SIGNAL FILTERING
JAN 21, 1976 01:55:04

RUN ID: A-893-1: DM3X-M

PROJECT: WHOLE BODY RESPONSE: DUMMY WITH TRIAXIALS AND BIAXIALS.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
61 -	1:	SLED DECELERATION	G'S	401	2007.	LP(030-090)	(4)
62 -	2:	RIGHT FEMUR LOAD	LBS	401	2007.	LP(090-225)	(5)
63 -	3:	LEFT FEMUR LOAD	LBS	401	2007.	LP(090-225)	(5)
64 -	4:	CHEST TRIAX P-A ACC	G'S	401	2007.	LP(090-225)	(5)
65 -	5:	CHEST TRIAX I-S ACC	G'S	401	2007.	LP(090-225)	(5)
66 -	6:	CHEST TRIAX R-L ACC	G'S	401	2007.	LP(090-225)	(5)
67 -	7:	PELVIS TRIAX I-S ACC	G'S	401	2007.	LP(090-225)	(5)
68 -	8:	PELVIS TRIAX P-A ACC	G'S	401	2007.	LP(090-225)	(5)
69 -	9:	PELVIS TRIAX R-L ACC	G'S	401	2007.	LP(090-225)	(5)
70 -	10:	HEAD TRIAX P-A ACC	G'S	401	2007.	LP(180-360)	(6)
71 -	11:	HEAD TRIAX I-S ACC	G'S	401	2007.	LP(180-360)	(6)
72 -	12:	HEAD TRIAX R-L ACC	G'S	401	2007.	LP(180-360)	(6)

FILES: 61 - 72 ON TAPE: GMR-F1 RUN: A-893-1: DM3X-M FILTERED JAN 21, 1976 01:56:45

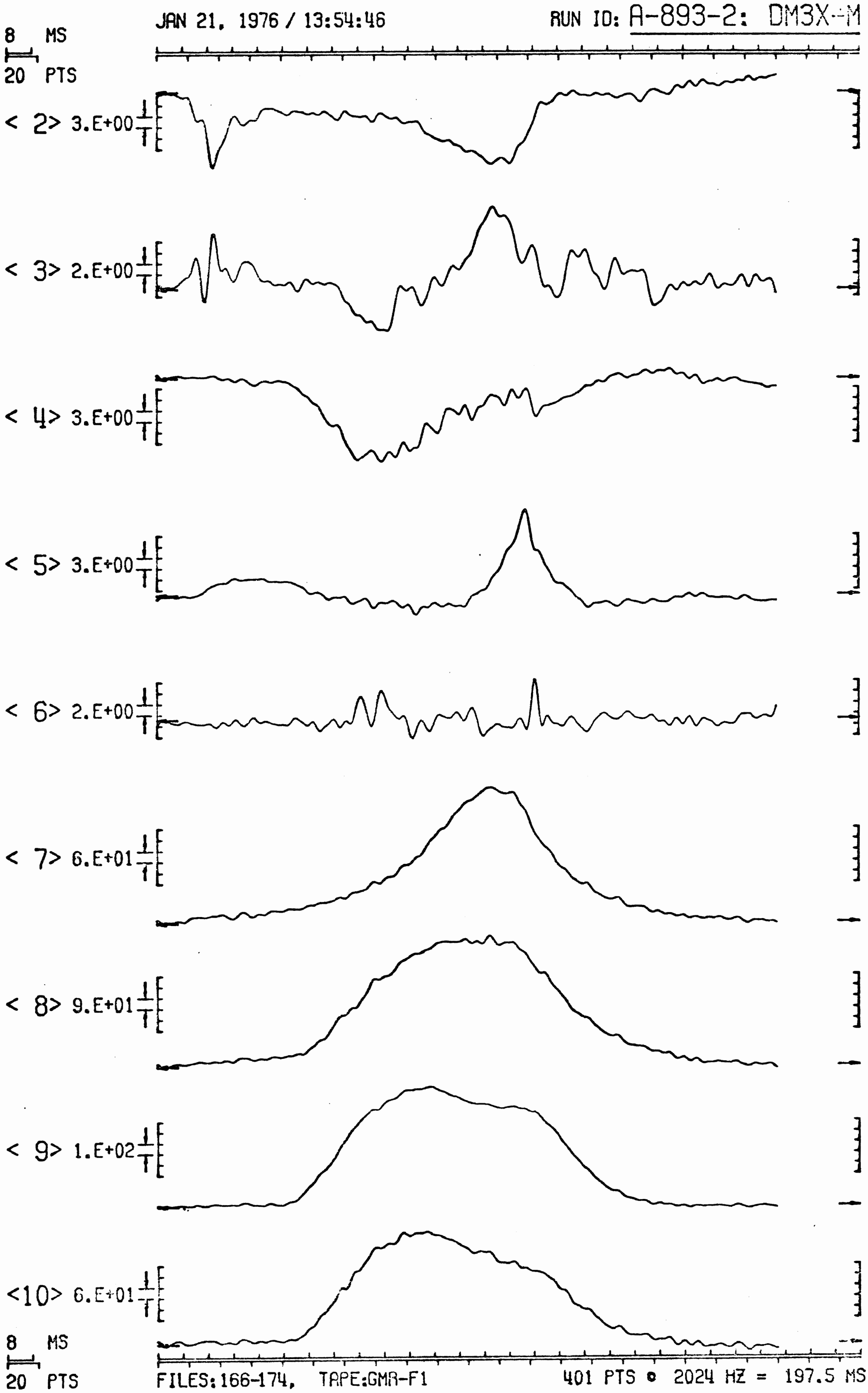

JAN 21, 1976 / 13:42:36
RUN ID: A-893-1: DM3X-M
8 MS
20 PTS
< 1> 2.E+00
< 2> 7.E+01
< 3> 6.E+01
< 4> 2.E+00
< 5> 3.E+00
< 6> 2.E+00
< 7> 2.E+00
< 8> 3.E+00
< 9> 3.E+00
<10> 5.E+00
<11> 4.E+00
<12> 9.E+00
8 MS
20 PTS
FILES: 61- 72, TAPE:GMR-F1
401 PTS @ 2007 HZ = 199.3 MS

TAPE: GMR-F1 | DIGITAL SIGNAL FILTERING JAN 21, 1976 02:17:46 | RUN ID: A-893-2: DM3X-M

PROJECT: WHOLE BODY RESPONSE.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
	1:						
166 -	2:	PELVIS EXT A-P ACC	G'S	401	2025.	LP(090-225)	(5)
167 -	3:	PELVIS EXT S-I ACC	G'S	401	2025.	LP(090-225)	(5)
168 -	4:	THORAX EXT A-P ACC	G'S	401	2025.	LP(090-225)	(5)
169 -	5:	THORAX EXT S-I ACC	G'S	401	2025.	LP(090-225)	(5)
170 -	6:	THORAX EXT L-R ACC	G'S	401	2025.	LP(090-225)	(5)
171 -	7:	RIGHT LAP BELT LOAD	LBS	401	2025.	LP(090-225)	(5)
172 -	8:	LEFT LAP BELT LOAD	LBS	401	2025.	LP(090-225)	(5)
173 -	9:	UPPER SHOULDER BELT LOAD	LBS	401	2025.	LP(090-225)	(5)
174 -	10:	LOWER SHOULDER BELT LOAD	LBS	401	2025.	LP(090-225)	(5)
	11:						
	12:						

FILES: 166 - 174 ON TAPE: GMR-F1 RUN: A-893-2: DM3X-M FILTERED JAN 21, 1976 02:18:16


JAN 21, 1976 / 13:54:46
RUN ID: A-893-2: DM3X-M
8 MS
20 PTS
< 2> 3.E+00
< 3> 2.E+00
< 4> 3.E+00
< 5> 3.E+00
< 6> 2.E+00
< 7> 6.E+01
< 8> 9.E+01
< 9> 1.E+02
<10> 6.E+01
8 MS
20 PTS
FILES:166-174, TAPE:GMR-F1
401 PTS @ 2024 HZ = 197.5 MS

TAPE: GMR-F1

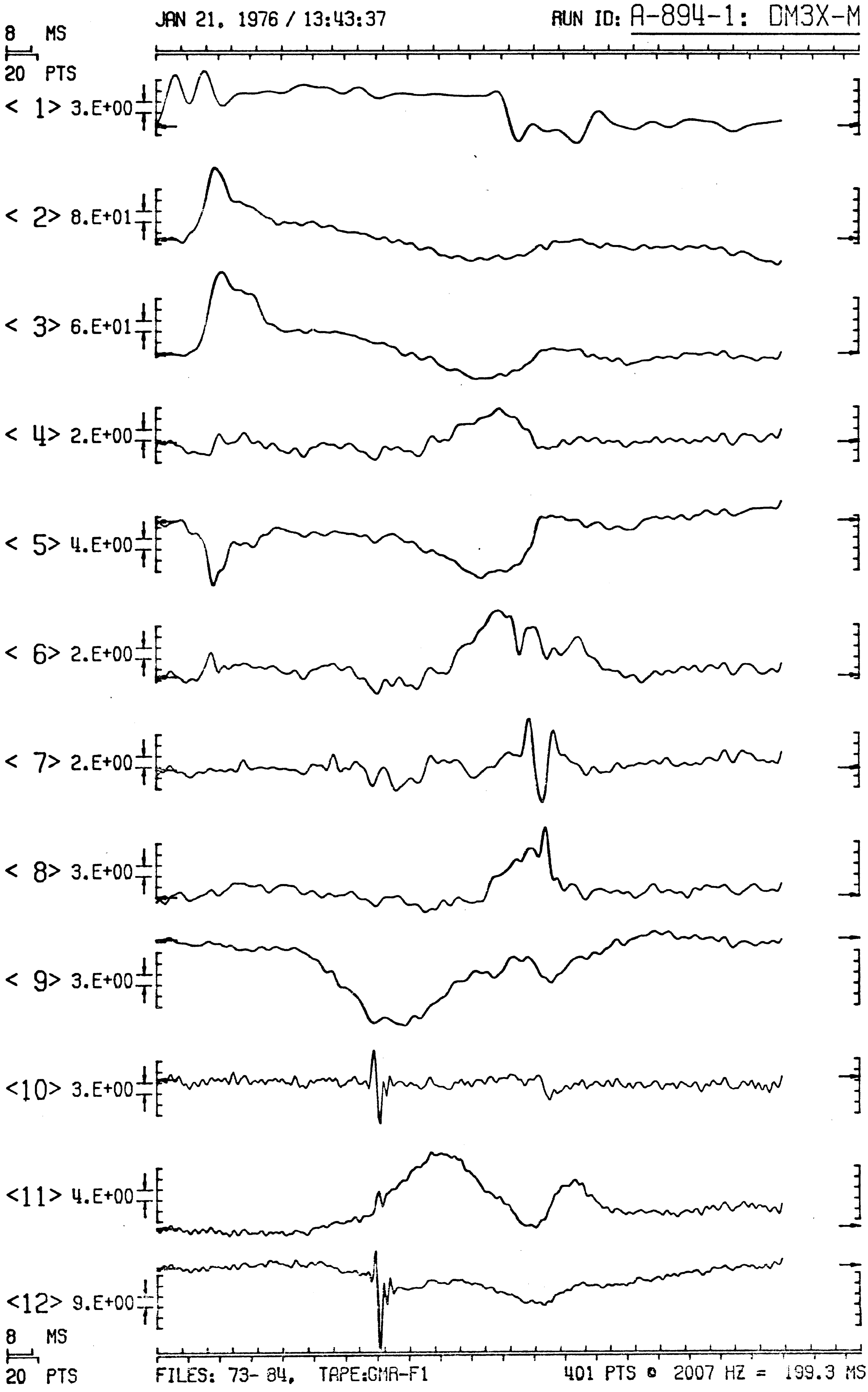
DIGITAL SIGNAL FILTERING
JAN 21, 1976 01:58:11

RUN ID: A-894-1: DM3X-M

PROJECT: WHOLE BODY RESPONSE: DUMMY WITH TRIAXIALS AND BIAXIALS.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
73 -	1:	SLED DECELERATION	G'S	401	2007.	LP(030-090)	(4)
74 -	2:	RIGHT FEMUR LOAD	LBS	401	2007.	LP(090-225)	(5)
75 -	3:	LEFT FEMUR LOAD	LBS	401	2007.	LP(090-225)	(5)
76 -	4:	CHEST TRIAX P-A ACC	G'S	401	2007.	LP(090-225)	(5)
77 -	5:	CHEST TRIAX I-S ACC	G'S	401	2007.	LP(090-225)	(5)
78 -	6:	CHEST TRIAX R-L ACC	G'S	401	2007.	LP(090-225)	(5)
79 -	7:	PELVIS TRIAX I-S ACC	G'S	401	2007.	LP(090-225)	(5)
80 -	8:	PELVIS TRIAX P-A ACC	G'S	401	2007.	LP(090-225)	(5)
81 -	9:	PELVIS TRIAX R-L ACC	G'S	401	2007.	LP(090-225)	(5)
82 -	10:	HEAD TRIAX P-A ACC	G'S	401	2007.	LP(180-360)	(6)
83 -	11:	HEAD TRIAX I-S ACC	G'S	401	2007.	LP(180-360)	(6)
84 -	12:	HEAD TRIAX R-L ACC	G'S	401	2007.	LP(180-360)	(6)

FILES: 73 - 84 ON TAPE: GMR-F1 RUN: A-894-1: DM3X-M FILTERED JAN 21, 1976 01:59:06


JAN 21, 1976 / 13:43:37
RUN ID: A-894-1: DM3X-M
8 MS
20 PTS
< 1> 3.E+00
< 2> 8.E+01
< 3> 6.E+01
< 4> 2.E+00
< 5> 4.E+00
< 6> 2.E+00
< 7> 2.E+00
< 8> 3.E+00
< 9> 3.E+00
<10> 3.E+00
<11> 4.E+00
<12> 9.E+00
8 MS
20 PTS
FILES: 73- 84, TAPE:GMR-F1
401 PTS @ 2007 HZ = 199.3 MS

TAPE: GMR-F1

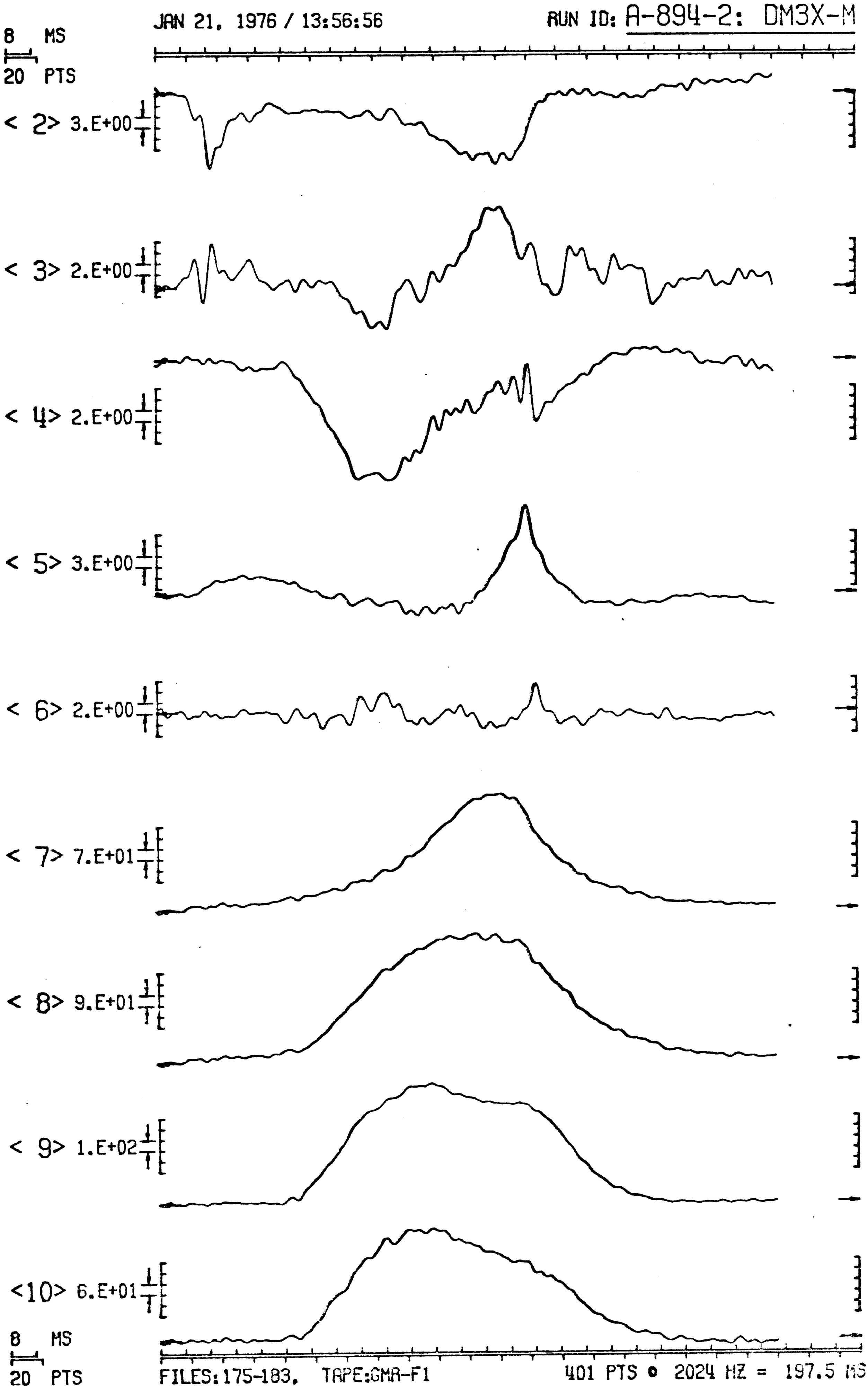
DIGITAL SIGNAL FILTERING
JAN 21, 1976 02:19:24

RUN ID: A-894-2: DM3X-M

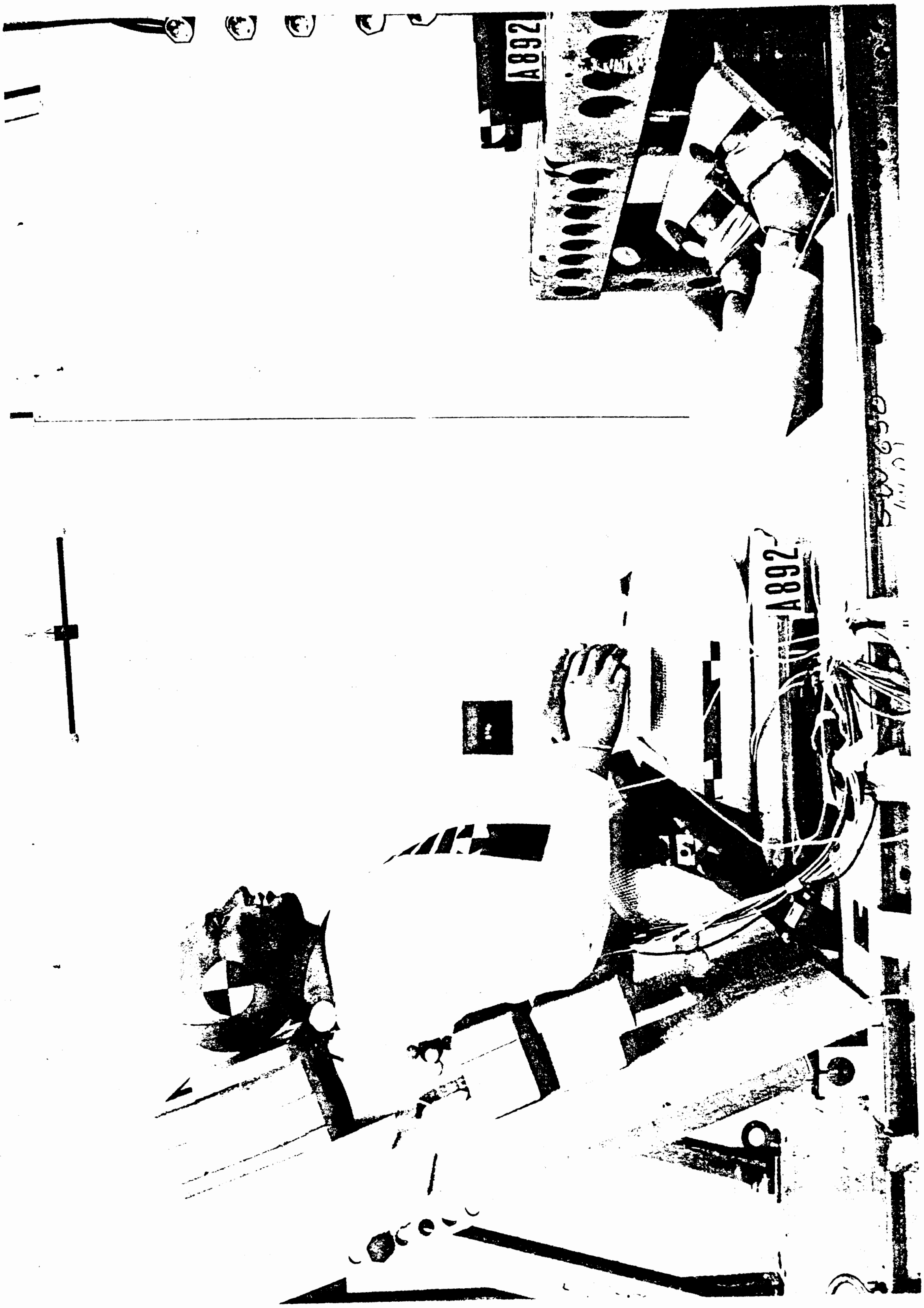
PROJECT: WHOLE BODY RESPONSE.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
	1:						
175 -	2:	PELVIS EXT A-P ACC	G'S	401	2025.	LP(090-225)	(5)
176 -	3:	PELVIS EXT S-I ACC	G'S	401	2025.	LP(090-225)	(5)
177 -	4:	THORAX EXT A-P ACC	G'S	401	2025.	LP(090-225)	(5)
178 -	5:	THORAX EXT S-I ACC	G'S	401	2025.	LP(090-225)	(5)
179 -	6:	THORAX EXT L-R ACC	G'S	401	2025.	LP(090-225)	(5)
180 -	7:	RIGHT LAP BELT LOAD	LBS	401	2025.	LP(090-225)	(5)
181 -	8:	LEFT LAP BELT LOAD	LBS	401	2025.	LP(090-225)	(5)
182 -	9:	UPPER SHOULDER BELT LOAD	LBS	401	2025.	LP(090-225)	(5)
183 -	10:	LOWER SHOULDER BELT LOAD	LBS	401	2025.	LP(090-225)	(5)
	11:						
	12:						

FILES: 175 - 183 ON TAPE: GMR-F1 RUN: A-894-2: DM3X-M FILTERED JAN 21, 1976 02:19:55

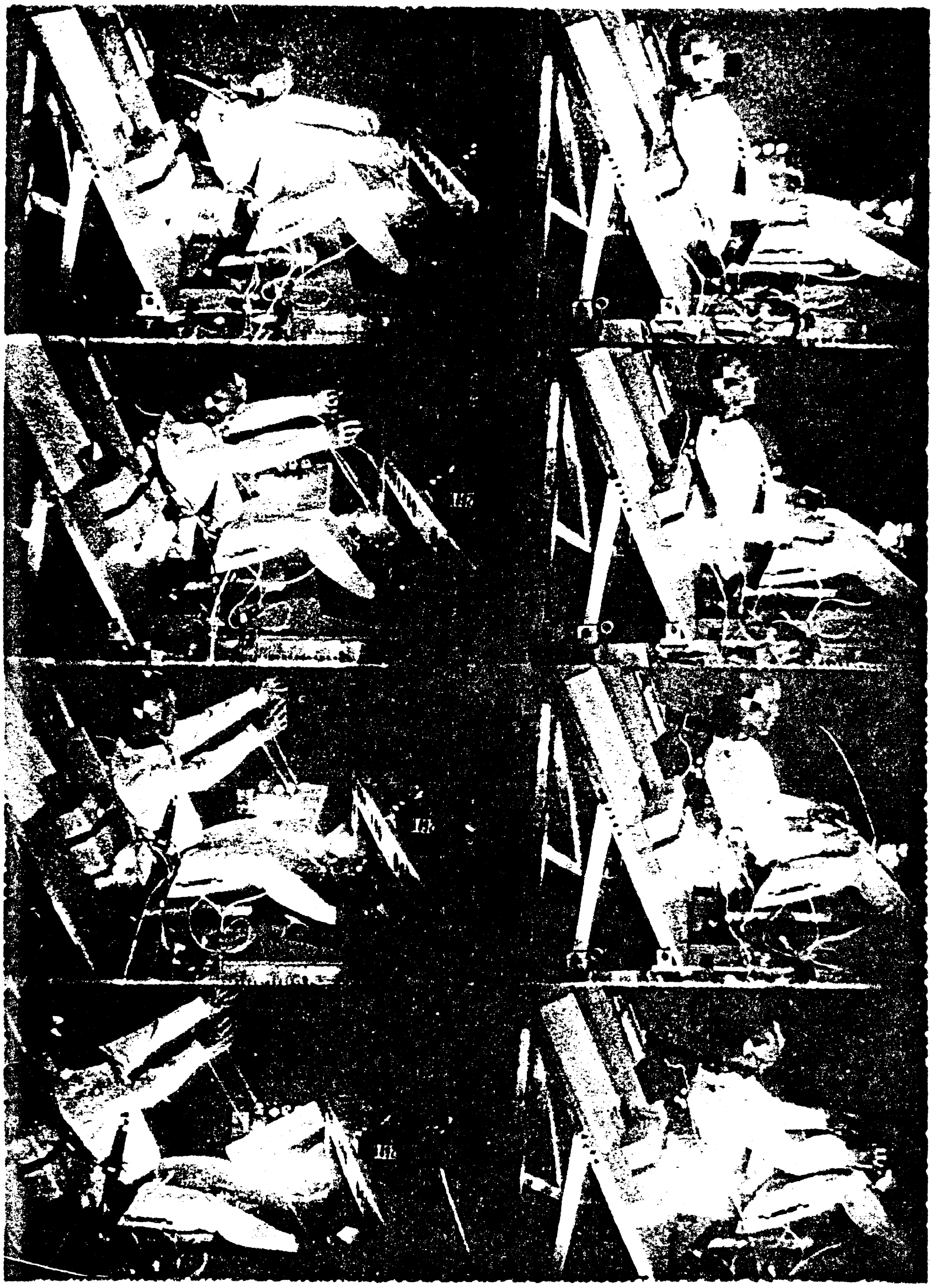


JAN 21, 1976 / 13:56:56
RUN ID: A-894-2: DM3X-M
8 MS
20 PTS
< 2> 3.E+00
< 3> 2.E+00
< 4> 2.E+00
< 5> 3.E+00
< 6> 2.E+00
< 7> 7.E+01
< 8> 9.E+01
< 9> 1.E+02
<10> 6.E+01
8 MS
20 PTS
FILES:175-183, TAPE:GMR-F1
401 PTS @ 2024 HZ = 197.5 MS



SETUP PHOTOGRAPH: TEST A-892

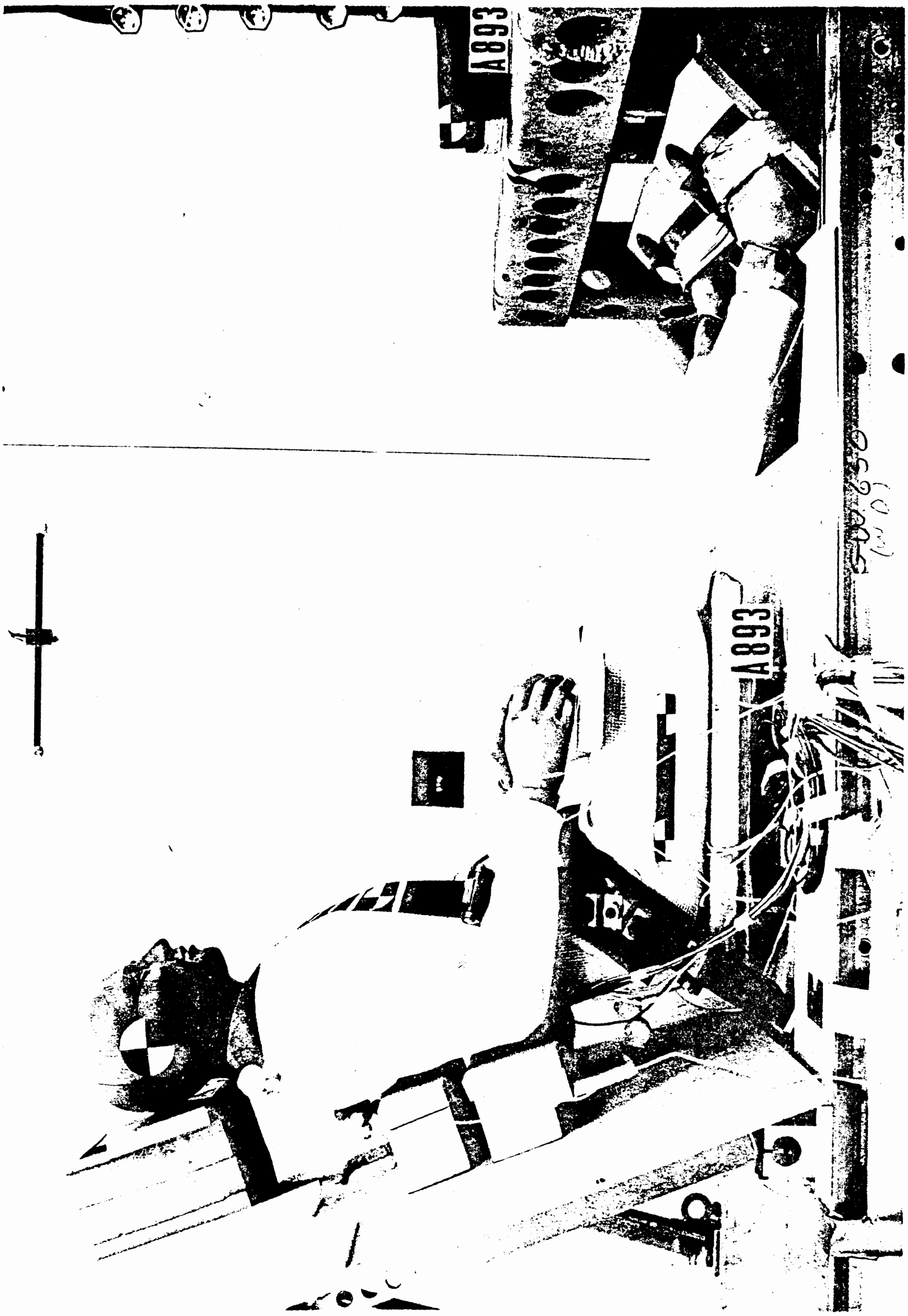
1



8

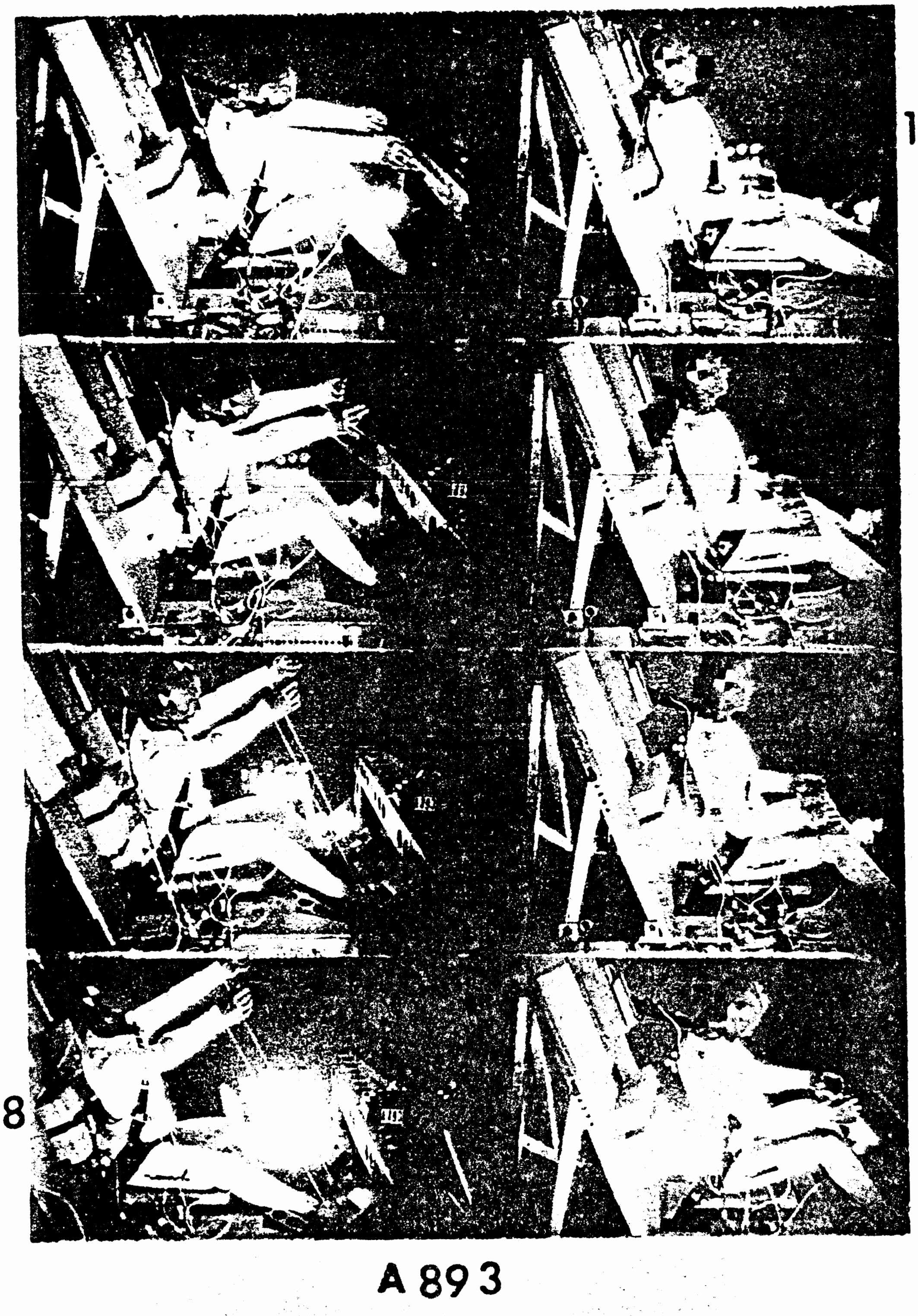
A892

GRAPHCHECK PHOTOGRAPH: TEST A-892

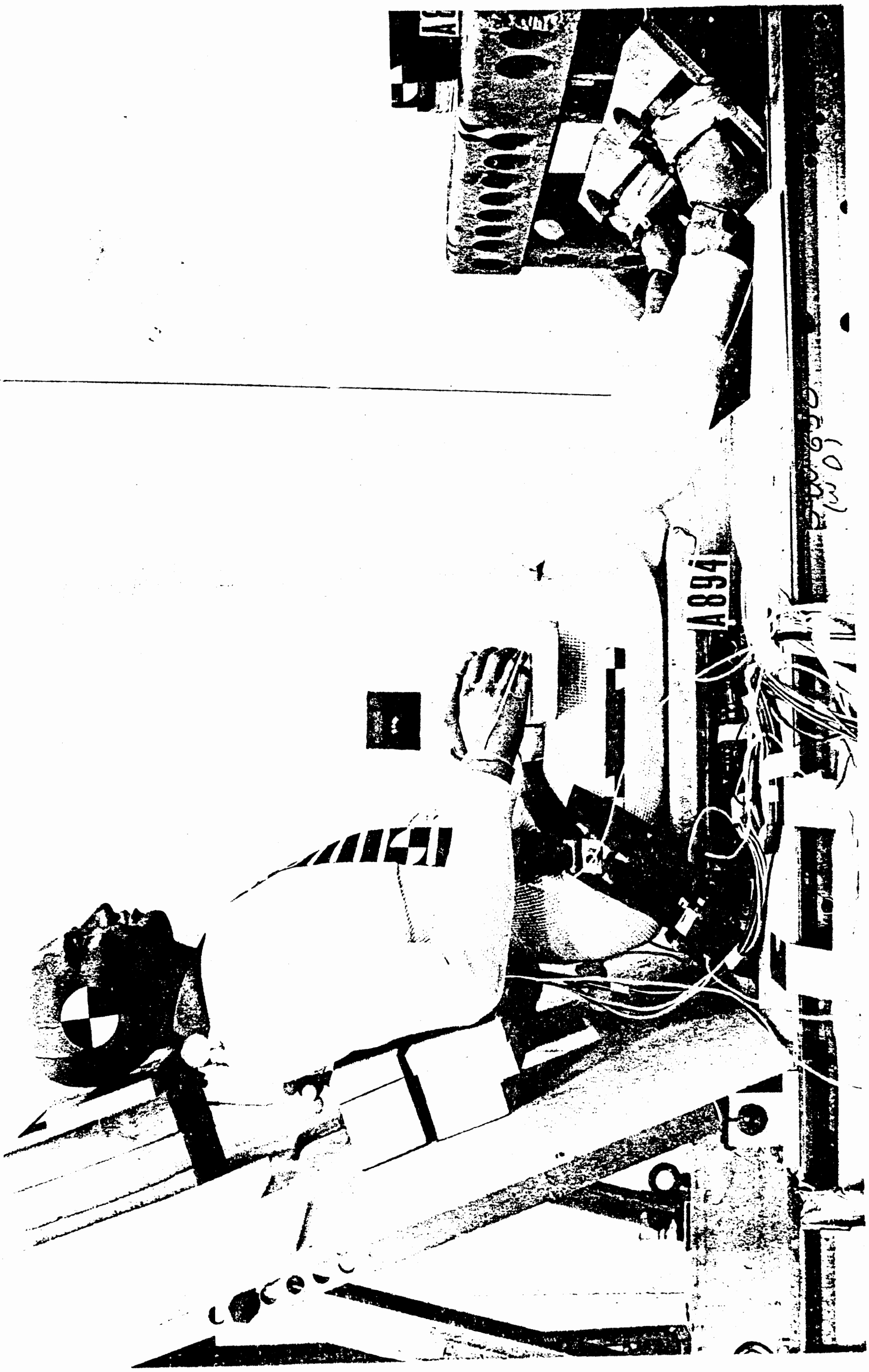


SETUP PHOTOGRAPH: TEST A-893

SETUP PHOTOGRAPH: TEST A-893

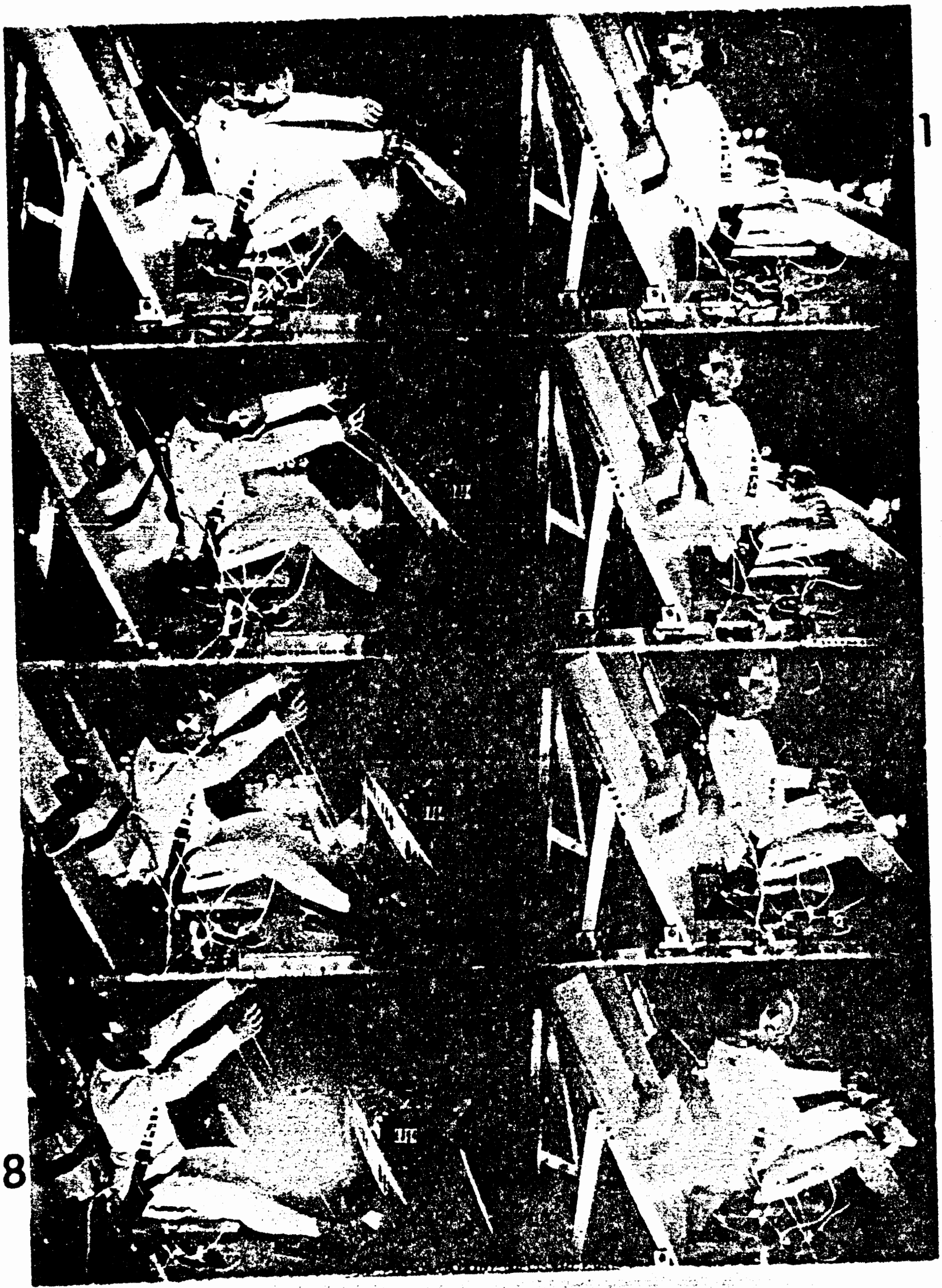


GRAPHCHECK PHOTOGRAPH: TEST A-893



SETUP PHOTOGRAPH: TEST A-894

SETUP PHOTOGRAPH: TEST A-894



A894

GRAPHCHECK PHOTOGRAPH: TEST A-894

WHOLE BODY RESPONSE

CERTIFIED DUMMY TEST

High Severity Impact

Type I Instrumentation

Frontal Impact

Three Point Belt Restraint

IMPACT PARAMETERS

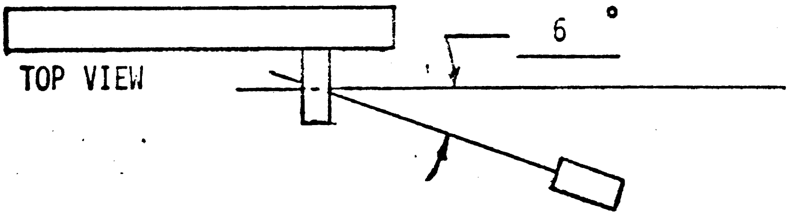
TEST NO.	IMPACT VELOCITY (MPH)	IMPACT DECELERATION (G's)
A-895	32.8	20.0
A-896	32.8	20.0
A-897	33.6	20.0

WBR# Certified Dummy

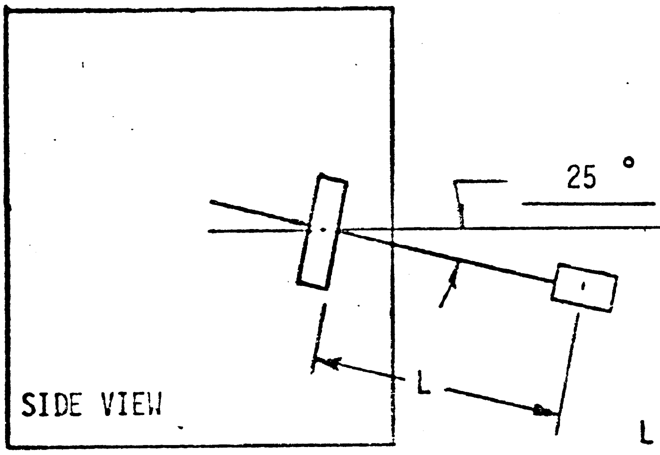
Test No. A-895

WHOLE BODY RESPONSE

BELT ANCHOR ORIENTATIONS

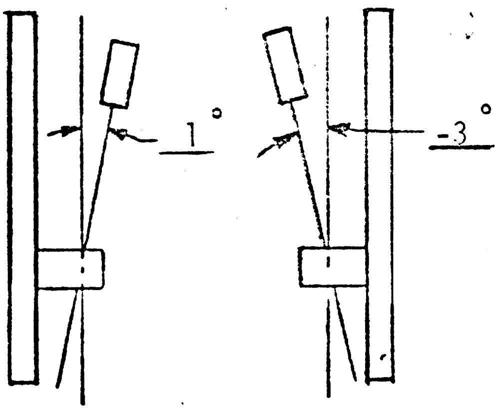


SHOULDER BELT



L = 6 7/8 in.

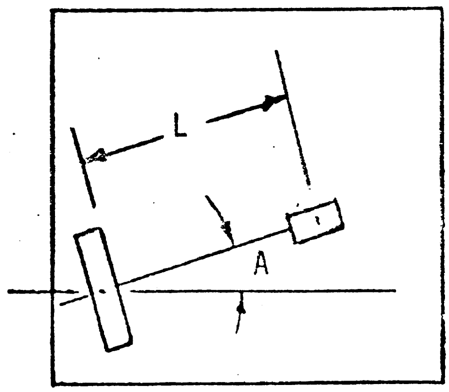
LAP BELT



LEFT SIDE

RIGHT SIDE

TOP VIEW



SIDE VIEW

L_{LEFT} = 5 5/8 in.

L_{RIGHT} = 5 1/2 in.

A_{LEFT} = 53 °

A_{RIGHT} = 57 °

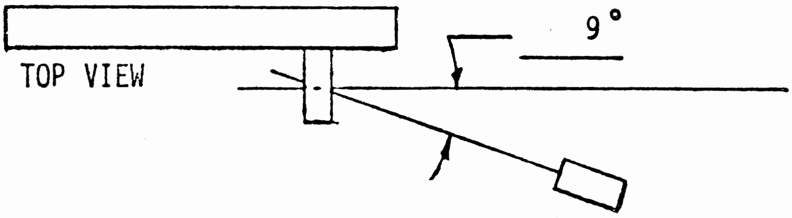
(Sketch indicates Positive Angle directions)

WBR# Certified Dummy

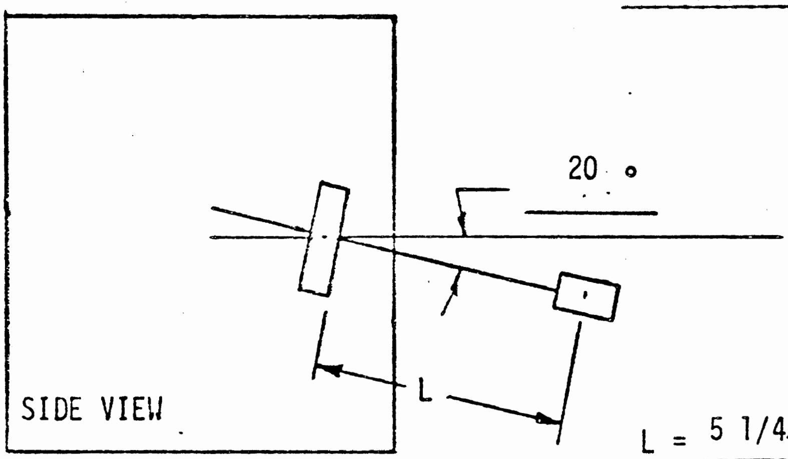
Test No. A-896

WHOLE BODY RESPONSE

BELT ANCHOR ORIENTATIONS

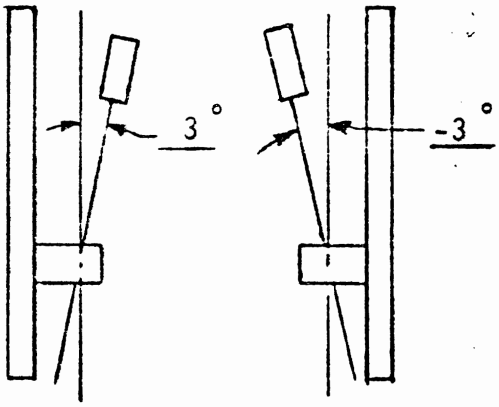


SHOULDER BELT



L = 5 1/4 in.

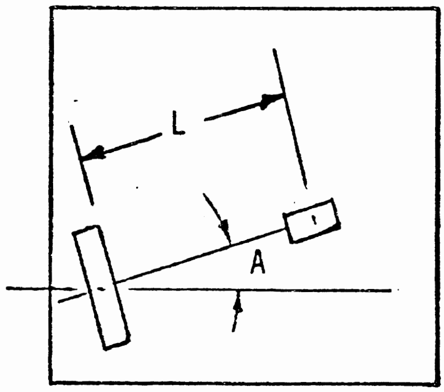
LAP BELT



LEFT SIDE

RIGHT SIDE

TOP VIEW



SIDE VIEW

L_{LEFT} = 4 1/4 in.

L_{RIGHT} = 6 3/8 in.

A_{LEFT} = 54 °

A_{RIGHT} = 60 °

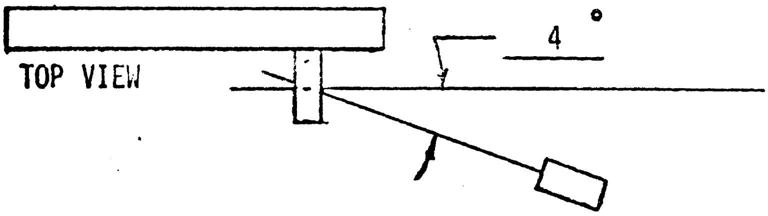
(Sketch indicates Positive Angle directions)

WBR# Certified Dummy

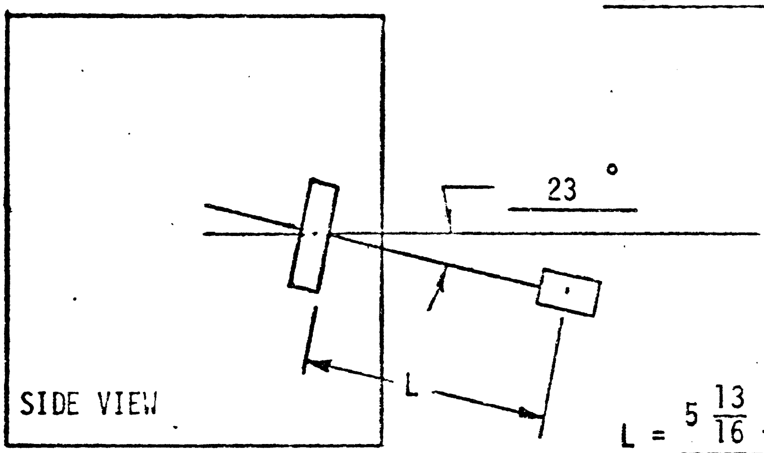
Test No. A-897

WHOLE BODY RESPONSE

BELT ANCHOR ORIENTATIONS

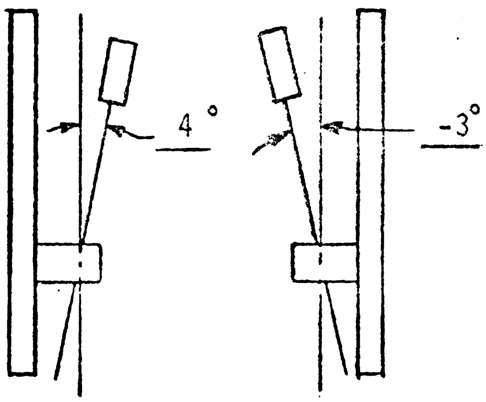


SHOULDER BELT



L = 5 13/16 in.

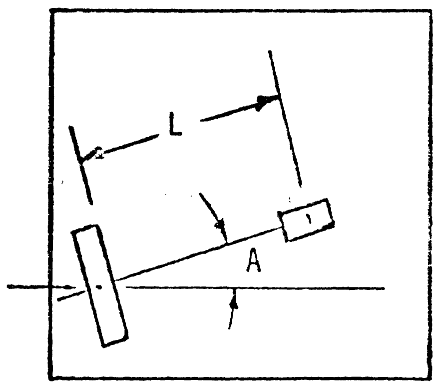
LAP BELT



LEFT SIDE

RIGHT SIDE

TOP VIEW



SIDE VIEW

L_{LEFT} = 5 1/8 in.

L_{RIGHT} = 6 1/16 in.

A_{LEFT} = 53 °

A_{RIGHT} = 60 °

(Sketch indicates Positive Angle directions)

WHOLE BODY RESPONSE WBR# Certified Dummy

BELT LENGTH DATA

TEST A- 895

Belt Position	Pre-Impact Length (in)	Post-Impact Length (in)	Belt Stretch (in)	Post-Impact Length with Load Cells
Rt. Lap	12	12 1/2	1/2	11 3/8
Lt. Lap	32 1/2	32 7/8	3/8	31 3/4
Shoulder	42	41 1/4	1/4	40 3/4

Test A- 896

Belt Position	Pre-Impact Length (in)	Post-Impact Length (in)	Belt Stretch (in)	Post-Impact Length with Load Cells
Rt. Lap	12	12 1/2	1/2	11 3/8
Lt. Lap	32 1/2	32 7/8	3/8	31 3/4
Shoulder	42	41 1/4	1/4	40 3/4

WHOLE BODY RESPONSE WBR# Certified Dummy

BELT LENGTH DATA

TEST A- 897

Belt Position	Pre-Impact Length (in)	Post-Impact Length (in)	Belt Stretch (in)	Post-Impact Length with Load Cells
Rt. Lap	12	12 1/8	1/8	11 3/8
Lt. Lap	32 1/2	32 1/2	0	31 7/8
Shoulder	42	42 1/4	1/4	40 3/4

Test A-________

Belt Position	Pre-Impact Length (in)	Post-Impact Length (in)	Belt Stretch (in)	Post-Impact Length with Load Cells
Rt. Lap				
Lt. Lap				
Shoulder				

TAPE: GMR-F1

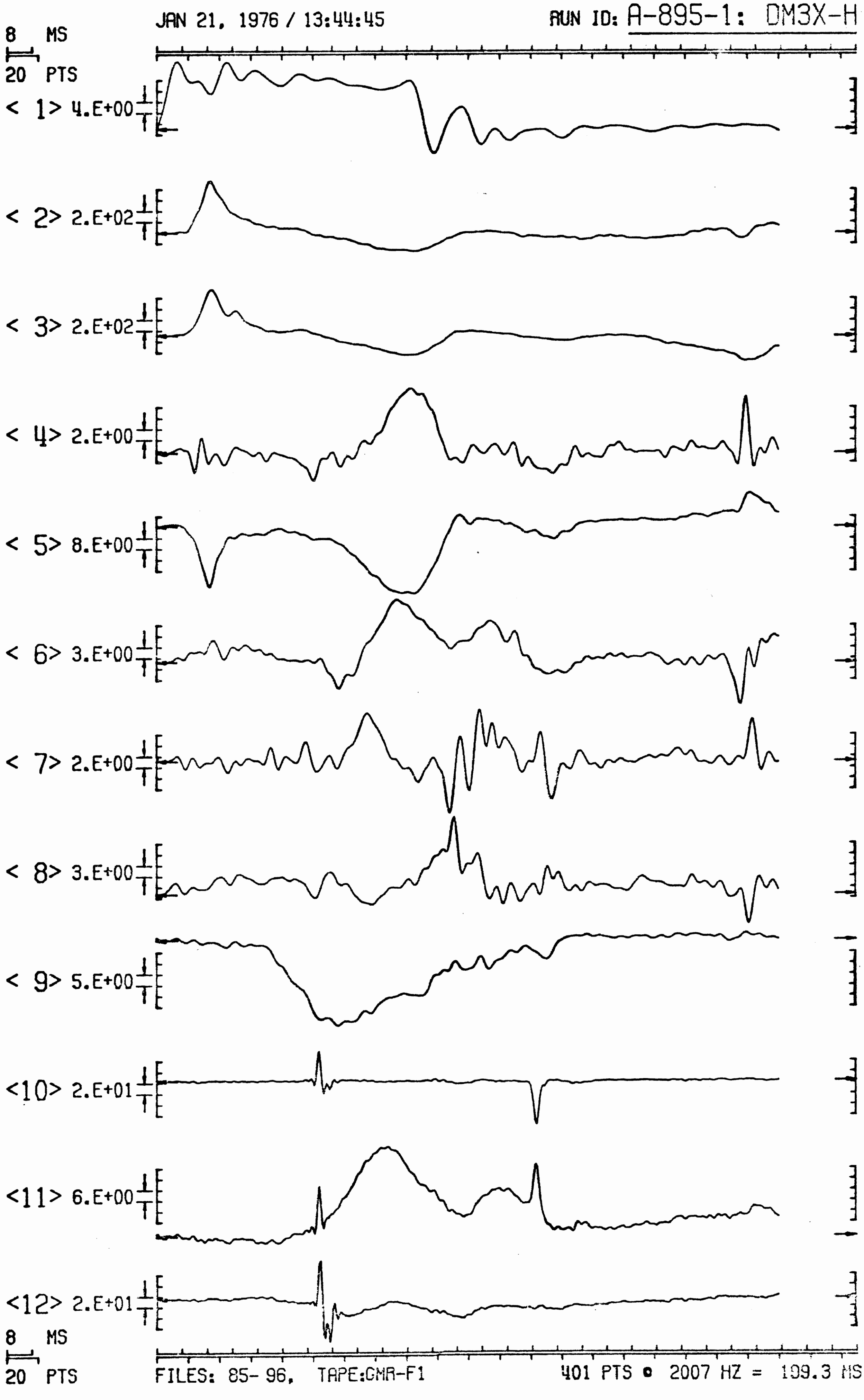
DIGITAL SIGNAL FILTERING
JAN 21, 1976 02:00:54

RUN ID: A-895-1: DM3X-H

PROJECT: WHOLE BODY RESPONSE: DUMMY WITH TRIAXIALS AND BIAXIALS.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
85 -	1:	SLED DECELERATION	G'S	401	2007.	LP(030-030)	(4)
86 -	2:	RIGHT FEMUR LOAD	LBS	401	2007.	LP(090-225)	(5)
87 -	3:	LEFT FEMUR LOAD	LBS	401	2007.	LP(090-225)	(5)
88 -	4:	CHEST TRIAX P-A ACC	G'S	401	2007.	LP(090-225)	(5)
89 -	5:	CHEST TRIAX I-S ACC	G'S	401	2007.	LP(090-225)	(5)
90 -	6:	CHEST TRIAX R-L ACC	G'S	401	2007.	LP(090-225)	(5)
91 -	7:	PELVIS TRIAX I-S ACC	G'S	401	2007.	LP(090-225)	(5)
92 -	8:	PELVIS TRIAX P-A ACC	G'S	401	2007.	LP(090-225)	(5)
93 -	9:	PELVIS TRIAX R-L ACC	G'S	401	2007.	LP(090-225)	(5)
94 -	10:	HEAD TRIAX P-A ACC	G'S	401	2007.	LP(180-360)	(6)
95 -	11:	HEAD TRIAX I-S ACC	G'S	401	2007.	LP(180-360)	(6)
96 -	12:	HEAD TRIAX R-L ACC	G'S	401	2007.	LP(180-360)	(6)

FILES: 85 - 96 ON TAPE: GMR-F1 RUN: A-895-1: DM3X-H FILTERED JAN 21, 1976 02:01:40


JAN 21, 1976 / 13:44:45
RUN ID: A-895-1: DM3X-H
8 MS
20 PTS
< 1> 4.E+00
< 2> 2.E+02
< 3> 2.E+02
< 4> 2.E+00
< 5> 8.E+00
< 6> 3.E+00
< 7> 2.E+00
< 8> 3.E+00
< 9> 5.E+00
<10> 2.E+01
<11> 6.E+00
<12> 2.E+01
8 MS
20 PTS
FILES: 85- 96, TAPE:CMR-F1
401 PTS @ 2007 HZ = 199.3 MS

DIGITAL SIGNAL FILTERING
JAN 21, 1976 02:20:53

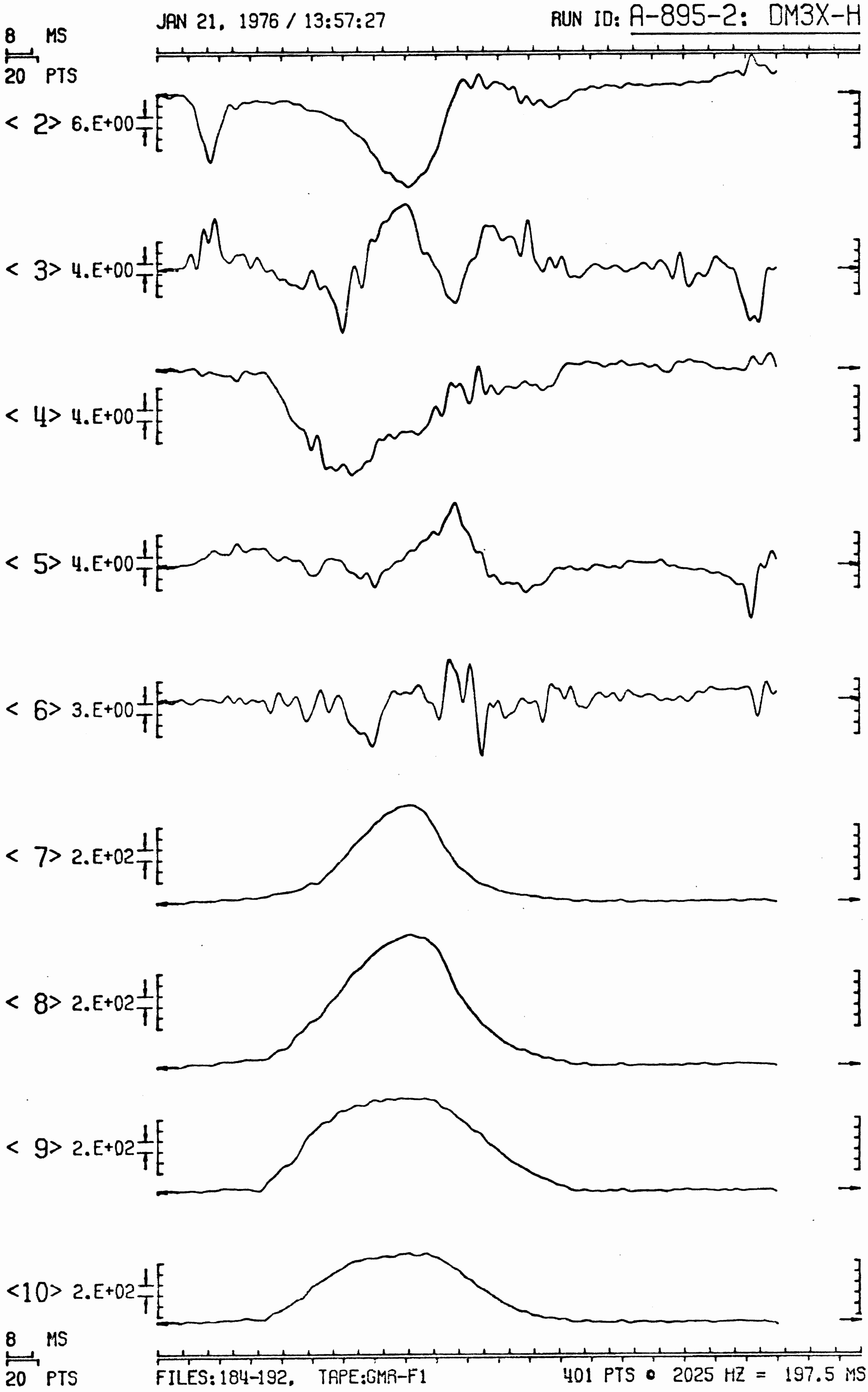
TAPE: GMR-F1

RUN ID: A-895-2: DM3X-H

PROJECT: WHOLE BODY RESPONSE.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
	1:						
184 -	2:	PELVIS EXT A-P ACC	G'S	401	2025.	LP(090-225)	(5)
185 -	3:	PELVIS EXT S-I ACC	G'S	401	2025.	LP(090-225)	(5)
186 -	4:	THORAX EXT A-P ACC	G'S	401	2025.	LP(090-225)	(5)
187 -	5:	THORAX EXT S-I ACC	G'S	401	2025.	LP(090-225)	(5)
188 -	6:	THORAX EXT L-R ACC	G'S	401	2025.	LP(090-225)	(5)
189 -	7:	RIGHT LAP BELT LOAD	LBS	401	2025.	LP(090-225)	(5)
190 -	8:	LEFT LAP BELT LOAD	LBS	401	2025.	LP(090-225)	(5)
191 -	9:	UPPER SHOULDER BELT LOAD	LBS	401	2025.	LP(090-225)	(5)
192 -	10:	LOWER SHOULDER BELT LOAD	LBS	401	2025.	LP(090-225)	(5)
	11:						
	12:						

FILES: 184 - 192 ON TAPE: GMR-F1 RUN: A-895-2: DM3X-H FILTERED JAN 21, 1976 02:21:23

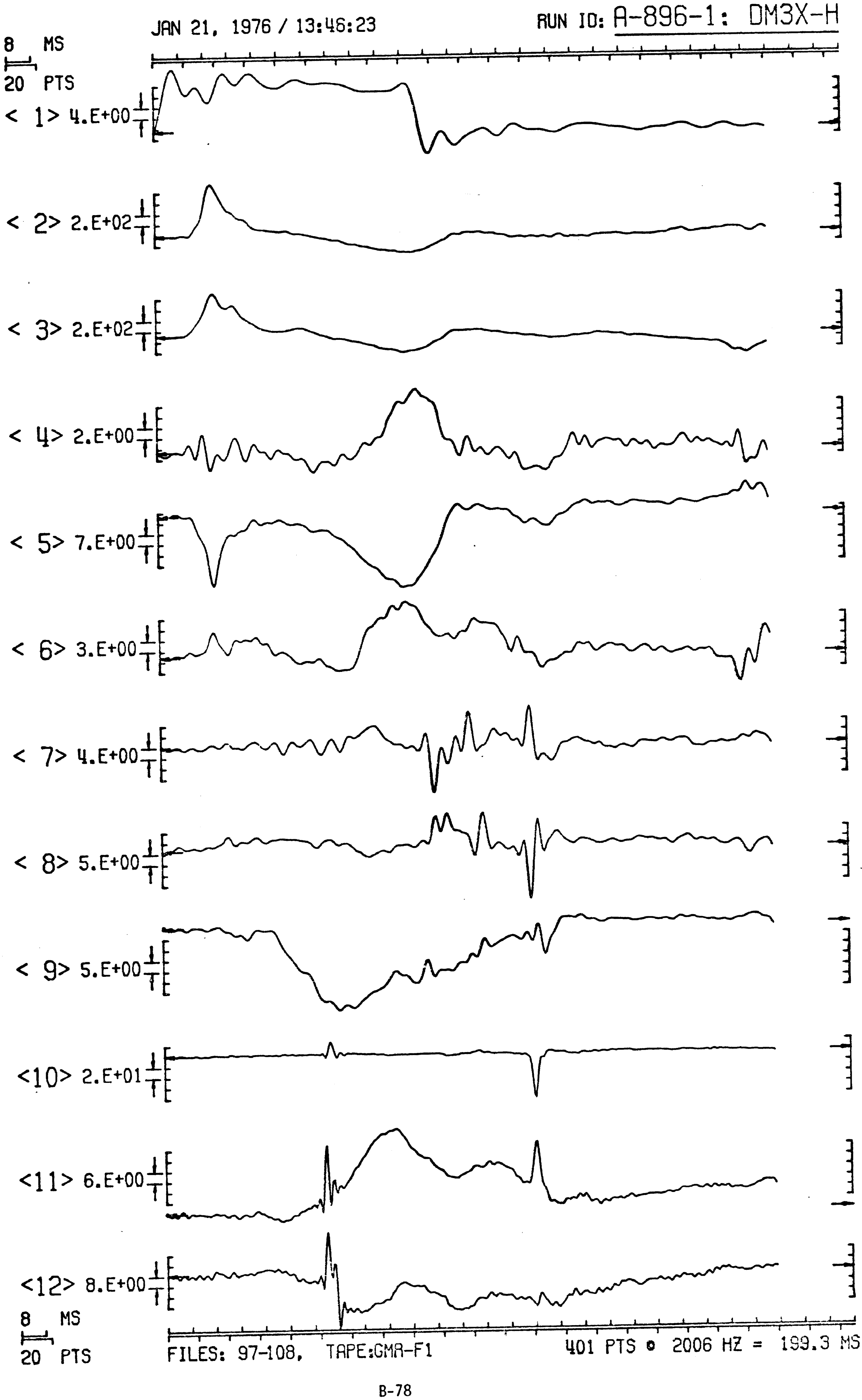

JAN 21, 1976 / 13:57:27
RUN ID: A-895-2: DM3X-H
8 MS
20 PTS
< 2> 6.E+00
< 3> 4.E+00
< 4> 4.E+00
< 5> 4.E+00
< 6> 3.E+00
< 7> 2.E+02
< 8> 2.E+02
< 9> 2.E+02
<10> 2.E+02
8 MS
20 PTS
FILES:184-192, TAPE:GMR-F1
401 PTS @ 2025 HZ = 197.5 MS

TAPE: GMR-F1 DIGITAL SIGNAL FILTERING JAN 21, 1976 02:03:05 RUN ID: A-896-1: DM3X-H

PROJECT: WHOLE BODY RESPONSE: DUMMY WITH TRIAXIALS AND BIAXIALS.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
97 -	1:	SLED DECELERATION	G'S	401	2007.	LP(030-090)	(4)
98 -	2:	RIGHT FEMUR LOAD	LBS	401	2007.	LP(090-225)	(5)
99 -	3:	LEFT FEMUR LOAD	LBS	401	2007.	LP(090-225)	(5)
100 -	4:	CHEST TRIAX P-A ACC	G'S	401	2007.	LP(090-225)	(5)
101 -	5:	CHEST TRIAX I-S ACC	G'S	401	2007.	LP(090-225)	(5)
102 -	6:	CHEST TRIAX R-L ACC	G'S	401	2007.	LP(090-225)	(5)
103 -	7:	PELVIS TRIAX I-S ACC	G'S	401	2007.	LP(090-225)	(5)
104 -	8:	PELVIS TRIAX P-A ACC	G'S	401	2007.	LP(090-225)	(5)
105 -	9:	PELVIS TRIAX R-L ACC	G'S	401	2007.	LP(090-225)	(5)
106 -	10:	HEAD TRIAX P-A ACC	G'S	401	2007.	LP(180-360)	(6)
107 -	11:	HEAD TRIAX I-S ACC	G'S	401	2007.	LP(180-360)	(6)
108 -	12:	HEAD TRIAX R-L ACC	G'S	401	2007.	LP(180-360)	(6)

FILES: 97 - 108 ON TAPE: GMR-F1 RUN: A-896-1: DM3X-H FILTERED JAN 21, 1976 02:03:52

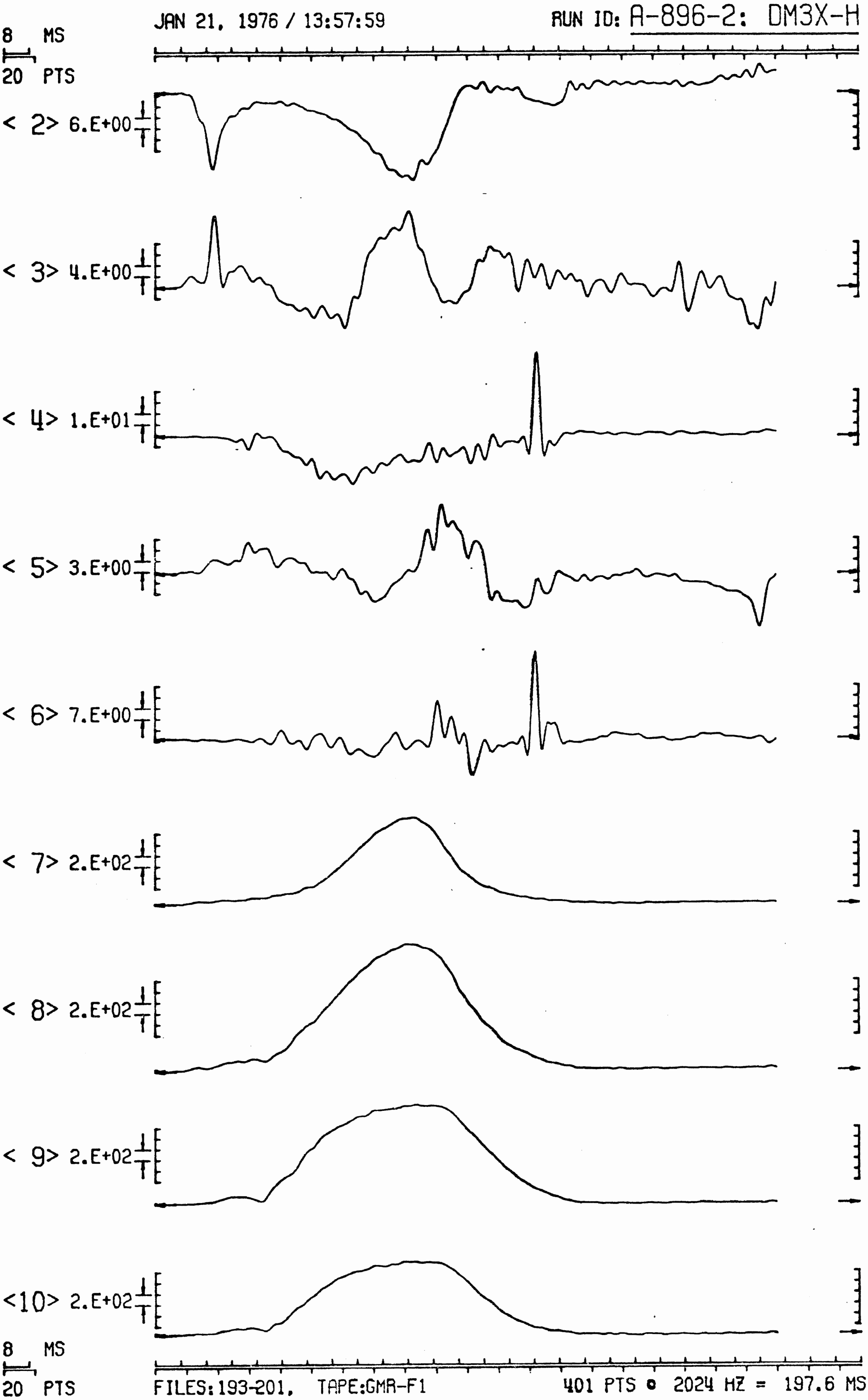

JAN 21, 1976 / 13:46:23
RUN ID: A-896-1: DM3X-H
8 MS
20 PTS
< 1> 4.E+00
< 2> 2.E+02
< 3> 2.E+02
< 4> 2.E+00
< 5> 7.E+00
< 6> 3.E+00
< 7> 4.E+00
< 8> 5.E+00
< 9> 5.E+00
<10> 2.E+01
<11> 6.E+00
<12> 8.E+00
8 MS
20 PTS
FILES: 97-108, TAPE:GMA-F1
401 PTS @ 2006 HZ = 199.3 MS

TAPE: GMR-F1 | DIGITAL SIGNAL FILTERING JAN 21, 1976 02:22:42 | RUN ID: A-896-2: DM3X-H

PROJECT: WHOLE BODY RESPONSE.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
	1:						
193 -	2:	PELVIS EXT A-P ACC	G'S	401	2025.	LP(090-225)	(5)
194 -	3:	PELVIS EXT S-I ACC	G'S	401	2025.	LP(090-225)	(5)
195 -	4:	THORAX EXT A-P ACC	G'S	401	2025.	LP(090-225)	(5)
196 -	5:	THORAX EXT S-I ACC	G'S	401	2025.	LP(090-225)	(5)
197 -	6:	THORAX EXT L-R ACC	G'S	401	2025.	LP(090-225)	(5)
198 -	7:	RIGHT LAP BELT LOAD	LBS	401	2025.	LP(090-225)	(5)
199 -	8:	LEFT LAP BELT LOAD	LBS	401	2025.	LP(090-225)	(5)
200 -	9:	UPPER SHOULDER BELT LOAD	LBS	401	2025.	LP(090-225)	(5)
201 -	10:	LOWER SHOULDER BELT LOAD	LBS	401	2025.	LP(090-225)	(5)
	11:						
	12:						

FILES: 193 - 201 ON TAPE: GMR-F1 RUN: A-896-2: DM3X-H FILTERED JAN 21, 1976 02:23:12



JAN 21, 1976 / 13:57:59
RUN ID: A-896-2: DM3X-H
8 MS
20 PTS
< 2> 6.E+00
< 3> 4.E+00
< 4> 1.E+01
< 5> 3.E+00
< 6> 7.E+00
< 7> 2.E+02
< 8> 2.E+02
< 9> 2.E+02
<10> 2.E+02
8 MS
20 PTS
FILES:193-201, TAPE:GMR-F1
401 PTS @ 2024 HZ = 197.6 MS

TAPE: GMR-F1

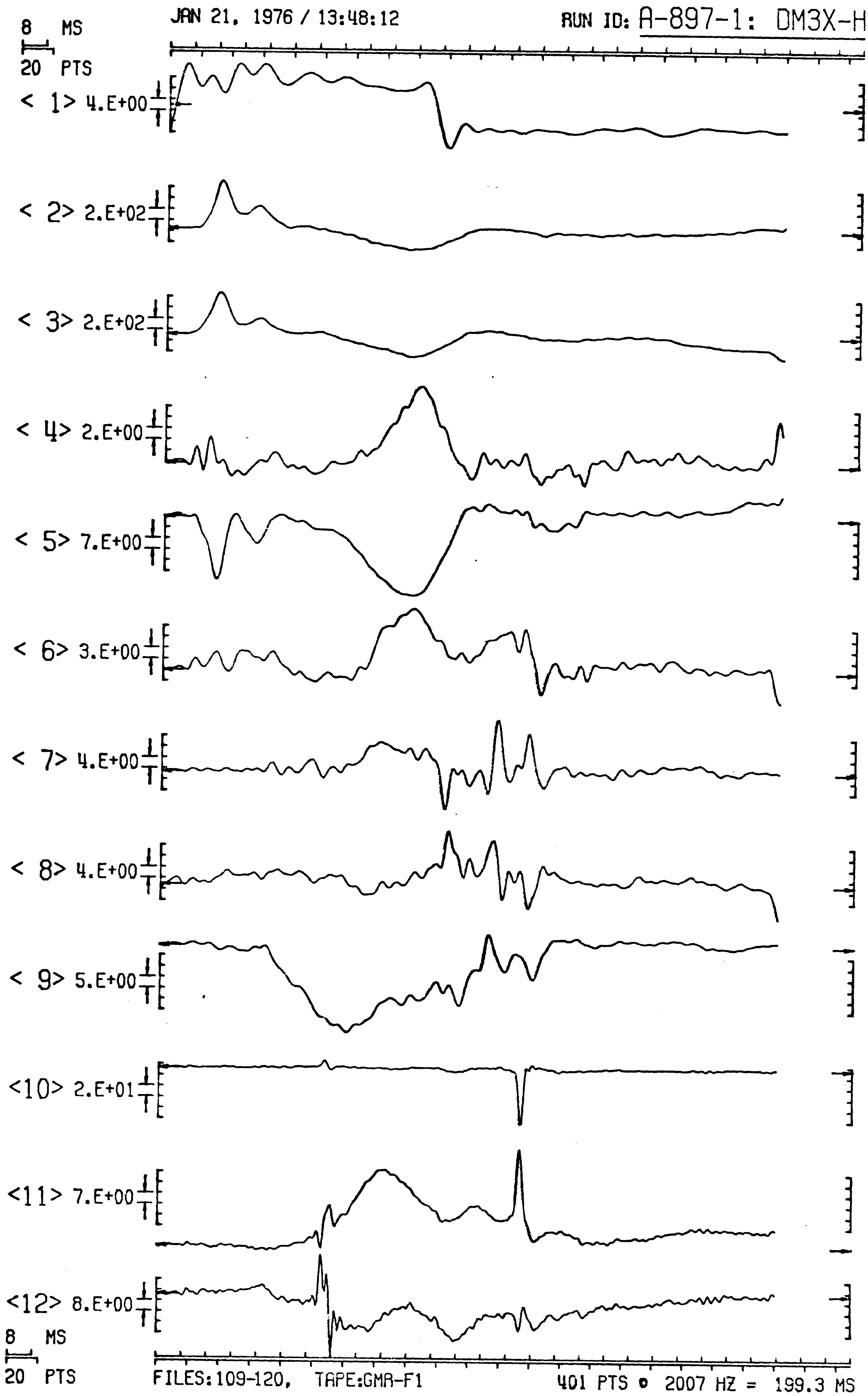
DIGITAL SIGNAL FILTERING
JAN 21, 1976 02:05:16

RUN ID: A-897-1: DM3X-H

PROJECT: WHOLE BODY RESPONSE: DUMMY WITH TRIAXIALS AND BIAXIALS.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
109 -	1:	SLED DECELERATION	G'S	401	2007.	LP(030-090)	(4)
110 -	2:	RIGHT FEMUR LOAD	LBS	401	2007.	LP(090-225)	(5)
111 -	3:	LEFT FEMUR LOAD	LBS	401	2007.	LP(090-225)	(5)
112 -	4:	CHEST TRIAX P-A ACC	G'S	401	2007.	LP(090-225)	(5)
113 -	5:	CHEST TRIAX I-S ACC	G'S	401	2007.	LP(090-225)	(5)
114 -	6:	CHEST TRIAX R-L ACC	G'S	401	2007.	LP(090-225)	(5)
115 -	7:	PELVIS TRIAX I-S ACC	G'S	401	2007.	LP(090-225)	(5)
116 -	8:	PELVIS TRIAX P-A ACC	G'S	401	2007.	LP(090-225)	(5)
117 -	9:	PELVIS TRIAX R-L ACC	G'S	401	2007.	LP(090-225)	(5)
118 -	10:	HEAD TRIAX P-A ACC	G'S	401	2007.	LP(180-360)	(6)
119 -	11:	HEAD TRIAX I-S ACC	G'S	401	2007.	LP(180-360)	(6)
120 -	12:	HEAD TRIAX R-L ACC	G'S	401	2007.	LP(180-360)	(6)

FILES: 109 - 120 ON TAPE: GMR-F1 RUN: A-897-1: DM3X-H FILTERED JAN 21, 1976 02:06:03



8 MS
20 PTS
JAN 21, 1976 / 13:48:12
RUN ID: A-897-1: DM3X-H
< 1> 4.E+00
< 2> 2.E+02
< 3> 2.E+02
< 4> 2.E+00
< 5> 7.E+00
< 6> 3.E+00
< 7> 4.E+00
< 8> 4.E+00
< 9> 5.E+00
<10> 2.E+01
<11> 7.E+00
<12> 8.E+00
8 MS
20 PTS
FILES:109-120, TAPE:GMA-F1
401 PTS @ 2007 HZ = 199.3 MS

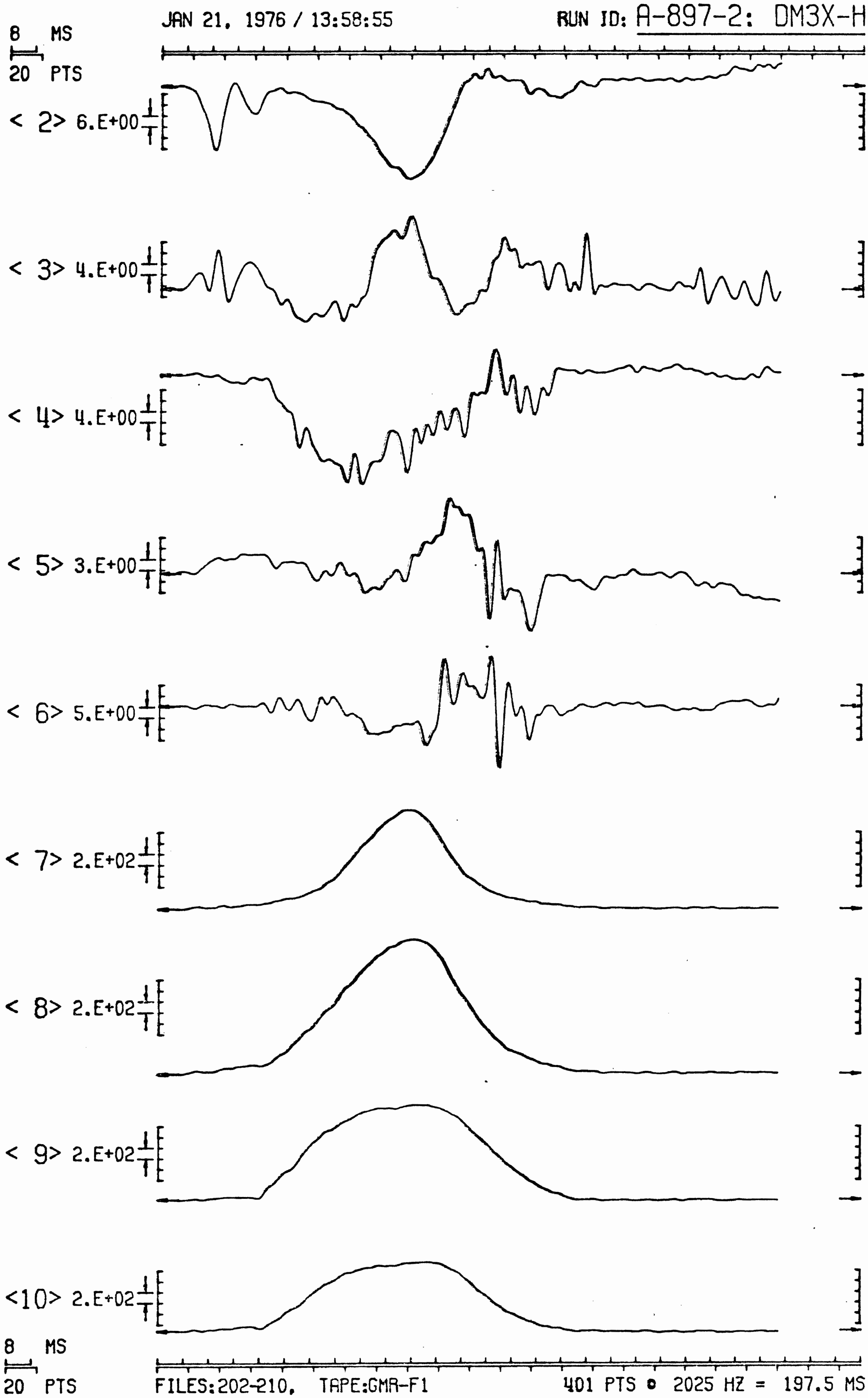
DIGITAL SIGNAL FILTERING

TAPE: GMR-F1 | JAN 21, 1976 02:24:12 | RUN ID: A-897-2: DM3X-H

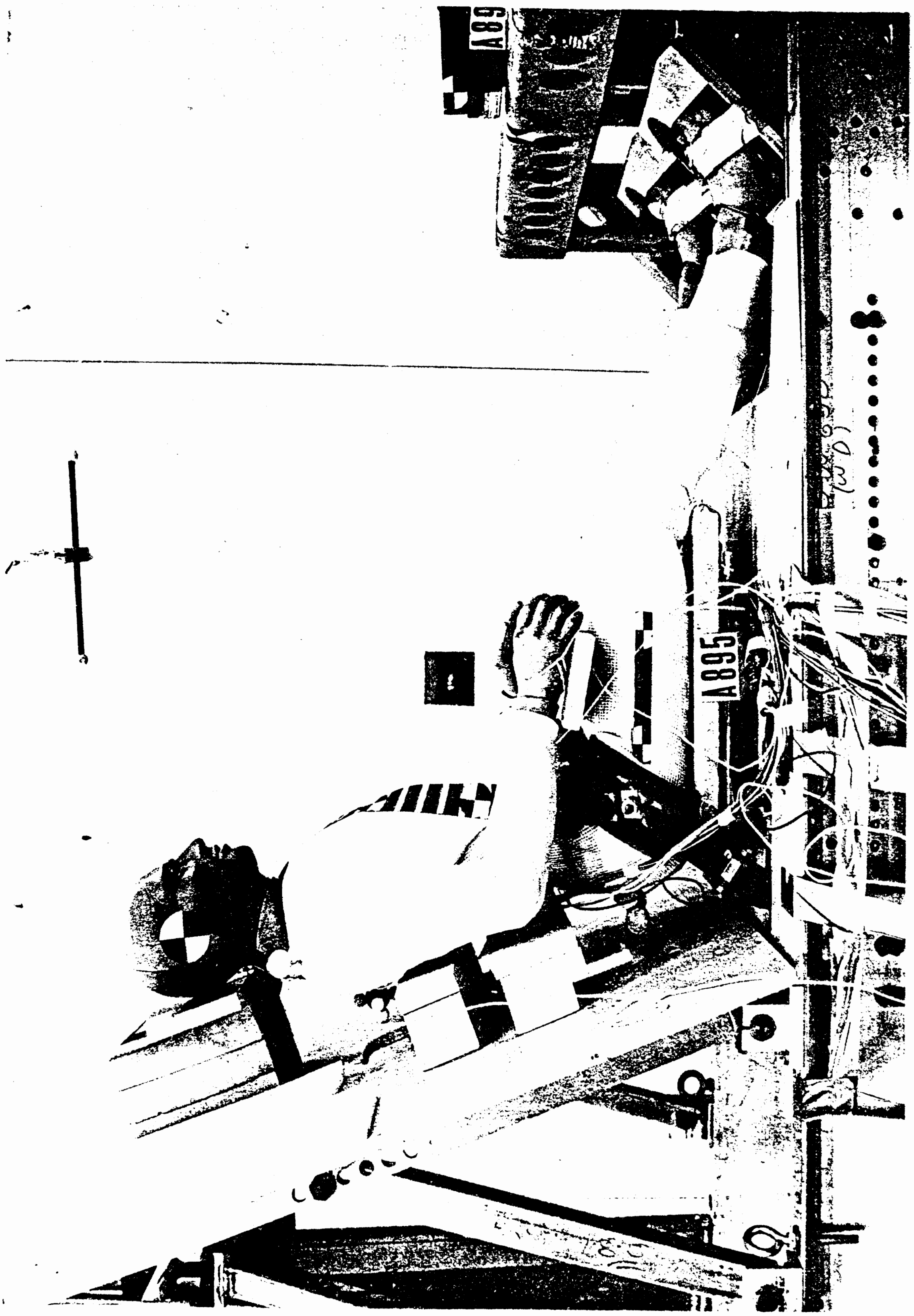
PROJECT: WHOLE BODY RESPONSE.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
	1:						
202 -	2:	PELVIS EXT A-P ACC	G'S	401	2025.	LP(090-225)	(5)
203 -	3:	PELVIS EXT S-I ACC	G'S	401	2025.	LP(090-225)	(5)
204 -	4:	THORAX EXT A-P ACC	G'S	401	2025.	LP(090-225)	(5)
205 -	5:	THORAX EXT S-I ACC	G'S	401	2025.	LP(090-225)	(5)
206 -	6:	THORAX EXT L-R ACC	G'S	401	2025.	LP(090-225)	(5)
207 -	7:	RIGHT LAP BELT LOAD	LBS	401	2025.	LP(090-225)	(5)
208 -	8:	LEFT LAP BELT LOAD	LBS	401	2025.	LP(090-225)	(5)
209 -	9:	UPPER SHOULDER BELT LOAD	LBS	401	2025.	LP(090-225)	(5)
210 -	10:	LOWER SHOULDER BELT LOAD	LBS	401	2025.	LP(090-225)	(5)
	11:						
	12:						

FILES: 202 - 210 ON TAPE: GMR-F1 RUN: A-897-2: DM3X-H FILTERED JAN 21, 1976 02:24:42



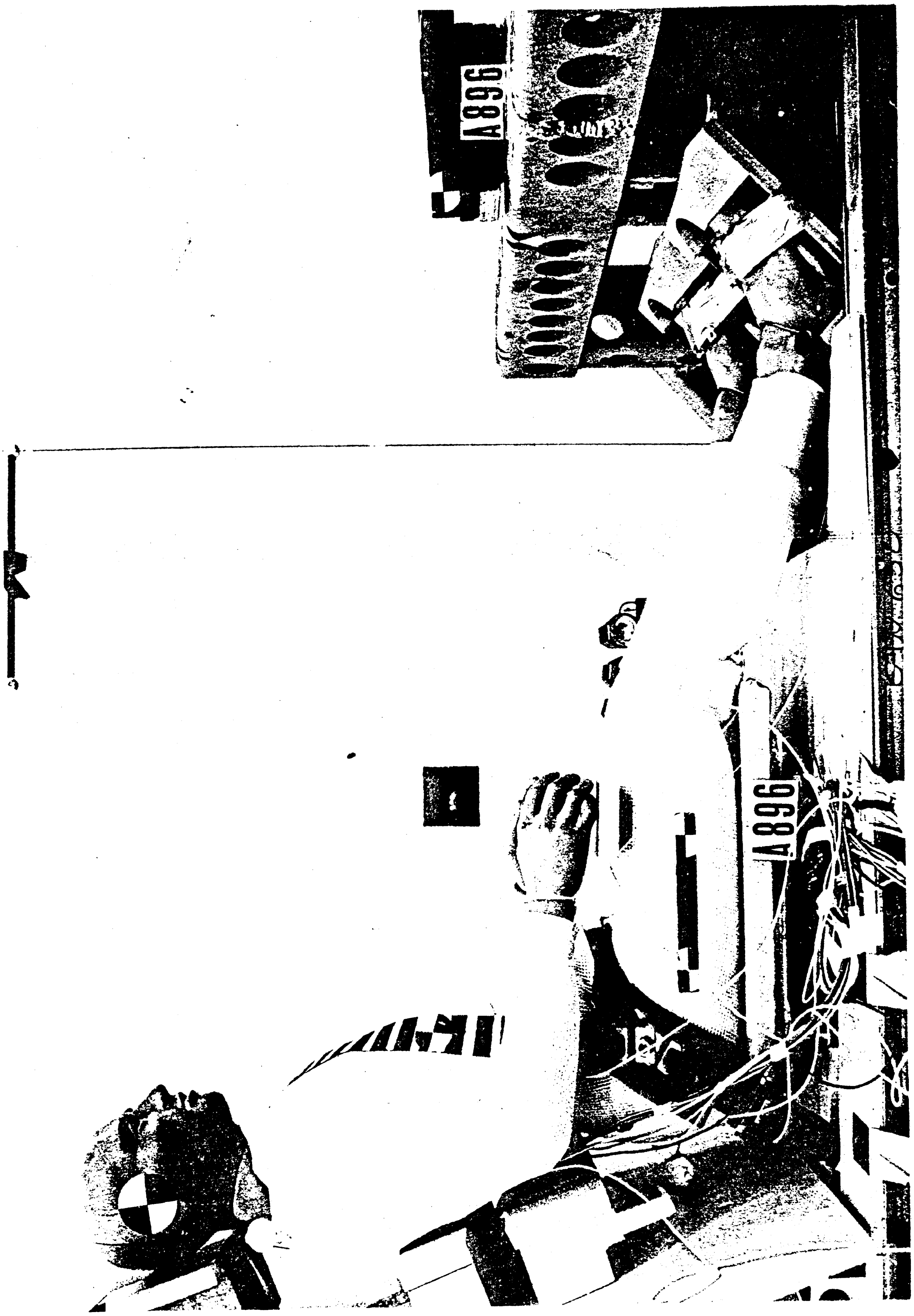
JAN 21, 1976 / 13:58:55
RUN ID: A-897-2: DM3X-H
8 MS
20 PTS
< 2> 6.E+00
< 3> 4.E+00
< 4> 4.E+00
< 5> 3.E+00
< 6> 5.E+00
< 7> 2.E+02
< 8> 2.E+02
< 9> 2.E+02
<10> 2.E+02
8 MS
20 PTS
FILES:202-210, TAPE:GMR-F1
401 PTS @ 2025 HZ = 197.5 MS



SETUP PHOTOGRAPH: TEST A-895

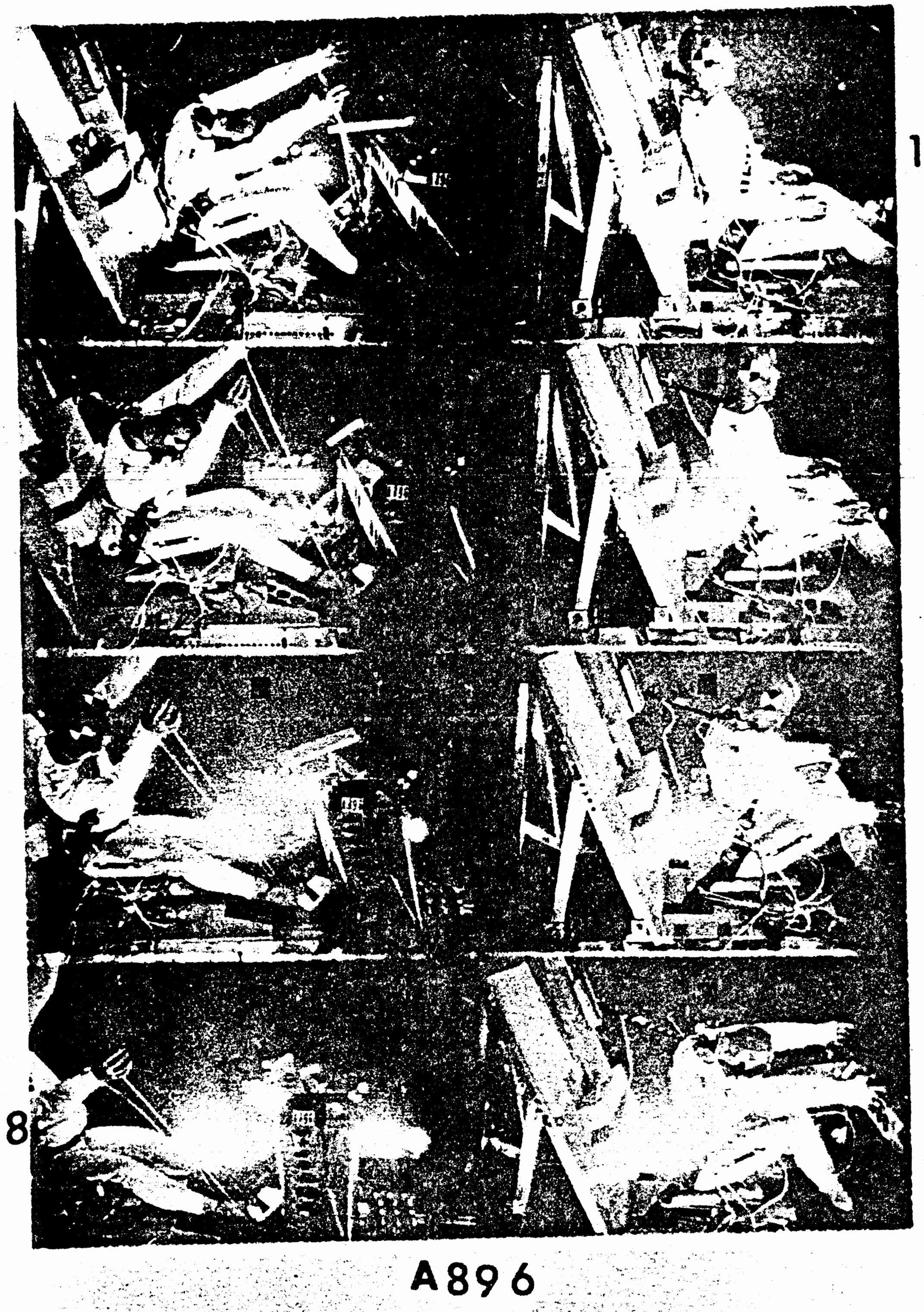
SETUP PHOTOGRAPH: TEST A-895

GRAPHCHECK PHOTOGRAPH: TEST A-895

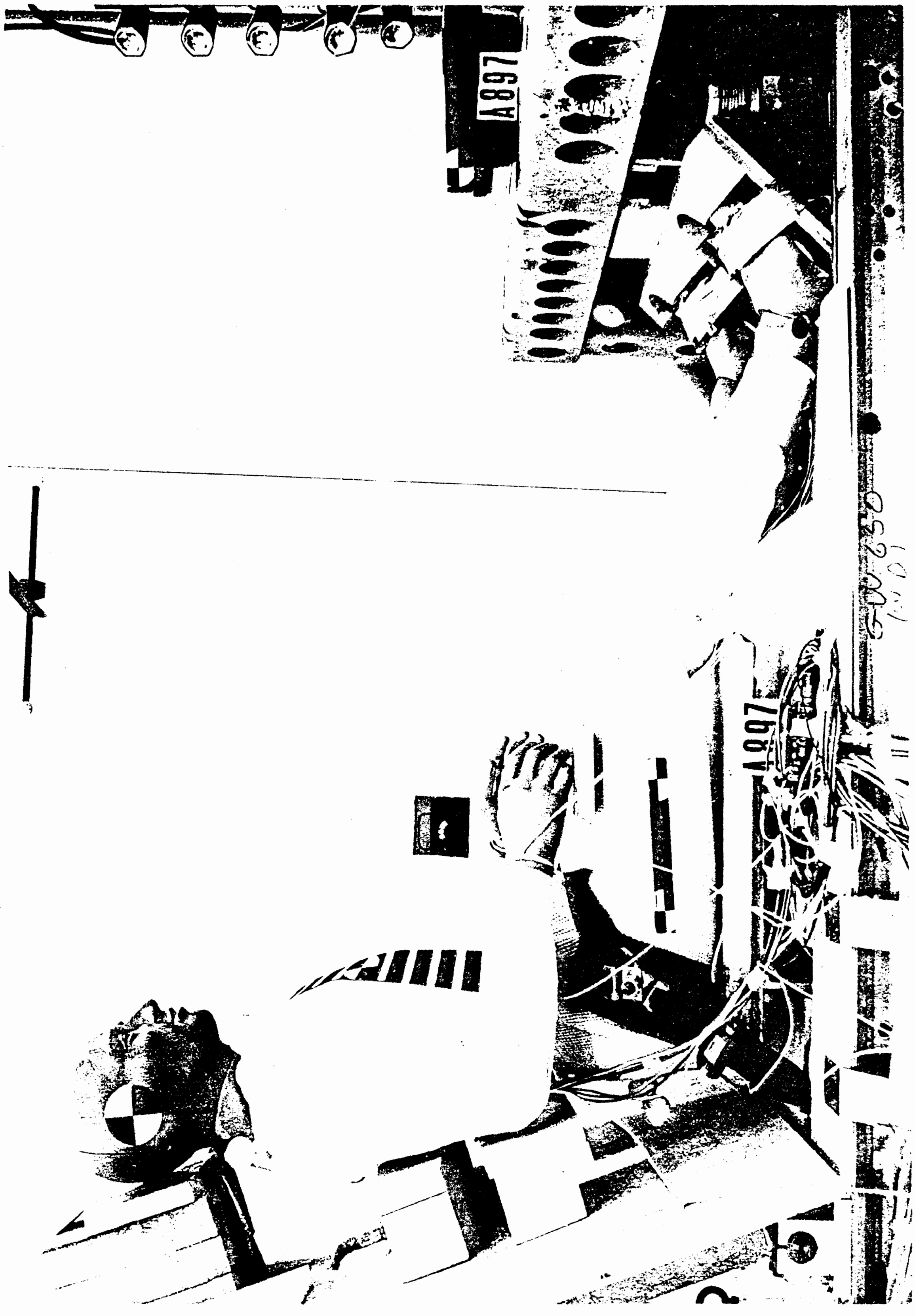


SETUP PHOTOGRAPH: TEST A-896

SETUP PHOTOGRAPH: TEST A-896



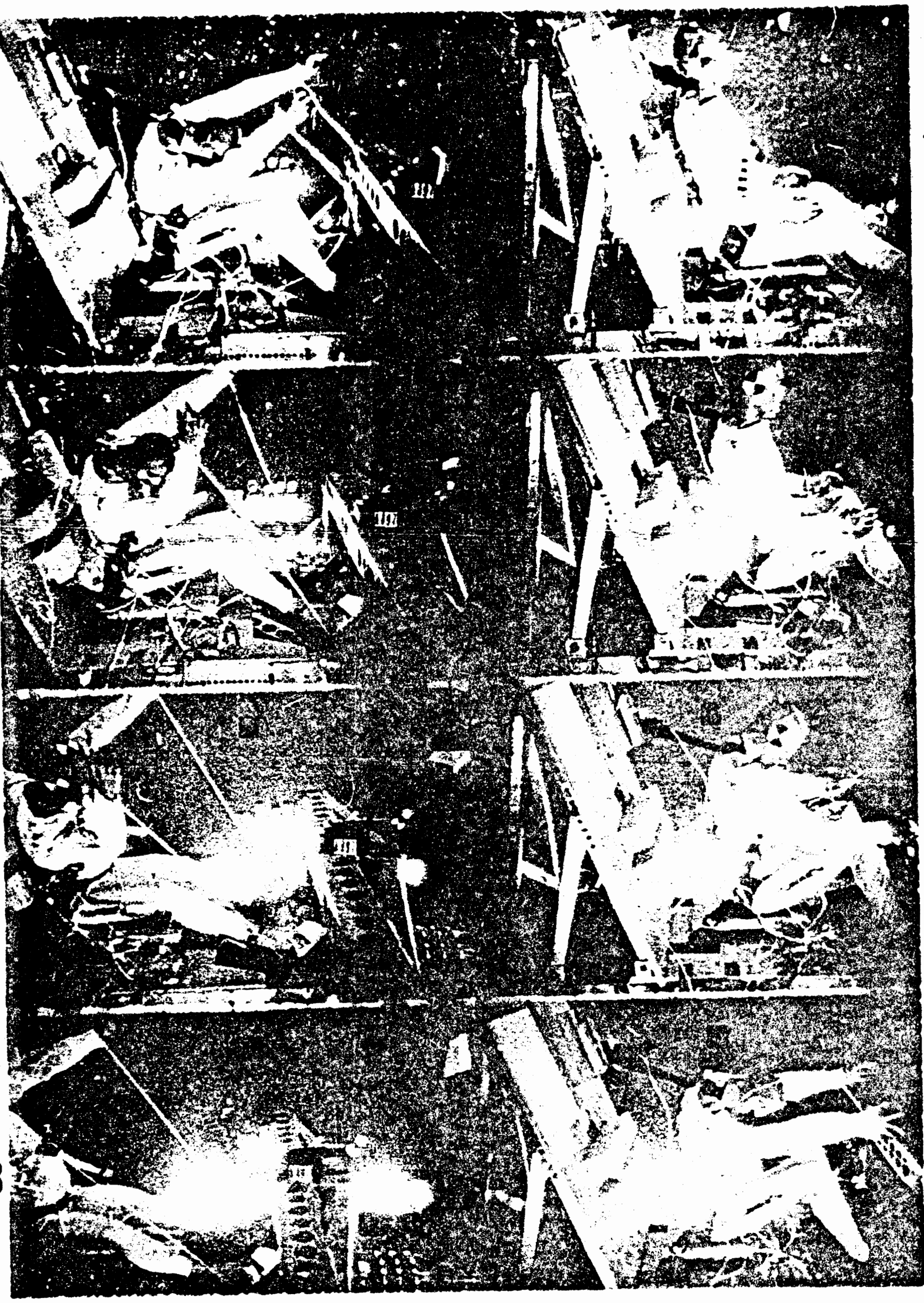
GRAPHCHECK PHOTOGRAPH: TEST A-896



SETUP PHOTOGRAPH: TEST A-897

SETUP PHOTOGRAPH: TEST A-897

1



8

A 897

GRAPHCHECK PHOTOGRAPH: TEST A-897

B.2 Type II Instrumentation

Type II instrumentation involved the addition of the three triaxial headset accelerometers for comparative purposes with the internal dummy head triax. The data recorded for this series included the following:

1. Nine Accelerometer Headset (Three Triaxial)
2. Head C.G. Triaxial Accelerometer (Inertial)
3. Thorax Triaxial Accelerometer (Cadaver Type Installation)
4. Pelvis Biaxial Accelerometer (Cadaver Type Installation)
5. Four Belt Webbing Forces

The data follows:

WHOLE BODY RESPONSE

CERTIFIED DUMMY TEST

Low Severity Impact

Type II Instrumentation

Frontal Impact

Three Point Belt Restraint

IMPACT PARAMETERS

TEST NO.	IMPACT VELOCITY (MPH)	IMPACT DECELERATION (G's)
A-907 (3" slack not in shoulder belt)	16.6	10.2
A-908	16.6	10.4
A-909	16.0	10.2
A-910	16.1	10.4

INSTRUMENTATION DATA SHEET

TEST NO. Certified Dummy SLED RUN NO. A-907 to A-913 DATE 8-22-75 PREPARED BY

TAPE DATA: RECORDER CEC ; TAPE # WBR ; RECORD SPEED = 30 IPS

CHAN.	INPUT	TAPE: 40% (3V) MODULATION VALUE	SET UP DATA: BARRIER STRIP #	SET UP DATA: AMPLIFIER NUMBER	SET UP DATA: AMPLIFIER GAIN	SET UP DATA: GAGE UNIT #	SET UP DATA: INPUT PANEL JACK #	SET UP DATA: UMBIL. CABLE #	TRANSDUCER: AXIS	TRANSDUCER: TYPE	TRANSDUCER: S/N	CALIBRATION: RESISTOR	CALIBRATION: VOLTAGE / GAIN	CALIBRATION: VALUE	OUTPUT SENSITIVITY	CHAN
1	Sled Decel.		B-1	H-1	200		H-1	26	-	Statham	13587		1.1 / 10	22.[illegible]	20 G/V	1
2	Pelvis P to A		B-14	H-14	100		H-14	14	-	Endevco	AC-14	199.4 K	-1.16 / 100	51.6G	-44.5 G/V	2
3	Pelvis I to S		B-15	H-15	100		H-15	15	-	"	AA-49	199.2 K	+1.29 / 100	66.8G	+51.8 G/V	3
4	Thorax P to A		B-16	H-16	100		H-16	16	-	"	AA-58	199.2 K	+1.23 / 100	56.2G	+45.7 G/V	4
5	Thorax I to S		B-17	H-17	100		H-17	17	-	"	AB-79	199.4 K	-1.16 / 100	52.5G	-45.3 G/V	5
6	Thorax R to L		B-18	H-18	100		H-18	18	-	"	AA-81	200.9 K	+1.28 / 100	50.9G	-39.8 G/V	6
7	Rt Lap		B-19	H-19	200		H-19	19	-	GSE	082	50 K	+2.20 / 200	2209#	+1000 #/V	7
8	Lt Lap		B-20	H-20	200		H-20	20	-	"	083	"	+2.24 / 200	2242#	+1000 #/V	8
9	Up Shoulder		B-29	CEC-1	X			22	-	"	084	"	+2.27 / 200	2277#	+1000 #/V	9
10	Low Shoulder		B-30	CEC-2	X			23	-	"	085	"	+2.94 / 200	2245#	+1000 #/V	10
11	Strobe		B-3	H-3	X			-								11
12	Velocity		B-4	H-4	10			Vel.							12.0"/pulse *4 is Tzero	12
13	Dig. Gate														280 msec	13
14	Time Base							TB							.01 sec/pulse	14

INSTRUMENTATION DATA SHEET

TEST NO. Certified Dummy SLED RUN NO. A-907 to A-913 DATE 8-22-75 PREPARED BY ____________

TAPE DATA: RECORDER 7600. ; TAPE # WBR ; RECORD SPEED = 30 IPS

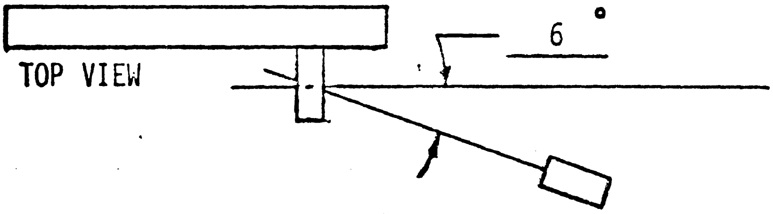
	TAPE		SET UP DATA						TRANSDUCER			CALIBRATION				
CHAN.	INPUT	40% (3V) MODULATION VALUE	BARRIER STRIP #	AMPLIFIER NUMBER	AMPLIFIER GAIN	GAGE UNIT #	INPUT PANEL JACK #	UMBIL. CABLE #	AXIS	TYPE	S/N	RESISTOR	VOLTAGE GAIN	VALUE	OUTPUT SENSITIVITY	CHAN
	Head Q_1		B-5	H-5	100		H-5	5	A	ENDEVCO UNIAX	AB-59	200.0 K	1.17/100	56.4G	-48.2 G/V	1
	Head Q_1		B-6	H-6	100		H-6	6	B	"	AB-60	199.6 K	-1.18/100	48.5G	-41.1 G/V	2
	Head Q_1		B-7	H-7	100		H-7	7	C	"	AB-61	199.4 K	-1.15/100	65.8G	-57.2 G/V	3
	Head Q_3		B-8	H-8	100		H-8	8	C	"	AB-85	199.5 K	-1.14/100	54.8G	-48.1 G/V	4
	Head Q_3		B-9	H-9	100		H-9	9	A	"	AB-87	199.5 K	-1.15/100	46.4G	-40.3 G/V	5
	Head Q_3		B-10	H-10	100		H-10	10	B	"	AB-90	199.6 K	-1.14/100	49.7G	-43.6 G/V	6
	Head Q_2		B-11	H-11	100		H-11	11	B	"	AB-97	199.4 K	-1.15/100	51.4G	-44.7 G/V	7
	Head Q_2		B-12	H-12	100		H-12	12	C	"	AC-04	199.4 K	-1.16/100	58.7G	-50.6 G/V	8
	Head Q_2		B-13	H-13	100		H-13	13	A	"	AC-06	199.5 K	-1.14/100	58.1G	-51.0 G/V	9
	Head AP		B-21	E-TX			ENDEVCO SIGNAL CONDITIONER		2	ENDEVCO TRIAX		199.1 K	-.99	63.2G	63.8 G/V	10
	Head SI		B-22	E-TX					1	"		"	-1.00	65.7G	65.7 G/V	11
	Head LR		B-23	E-TX					3	"	--	"	-.96	69.1G	72.0 G/V	12
	Digital Gate														280 msec	13
	Time Base							TB							.01 sec/pulse	14

WBR# Certified Dummy

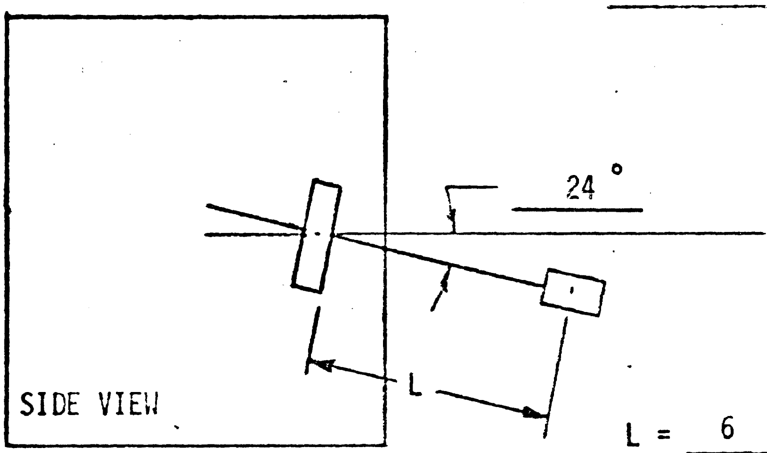
Test No. A-907

WHOLE BODY RESPONSE

BELT ANCHOR ORIENTATIONS

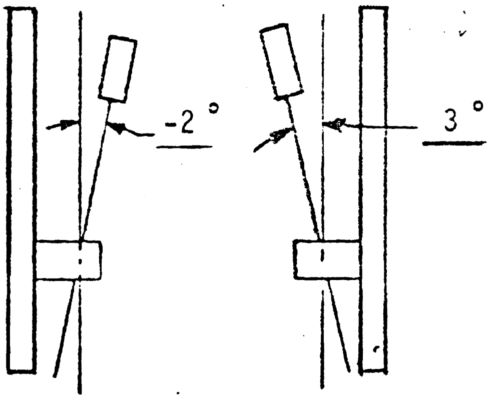


SHOULDER BELT



L = 6 in.

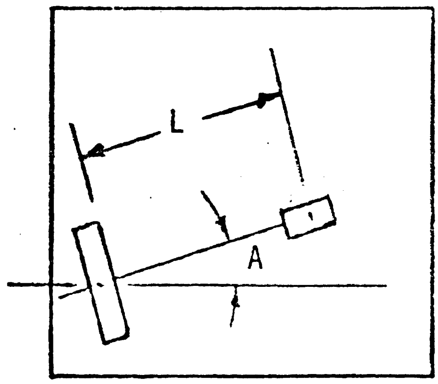
LAP BELT



LEFT SIDE

RIGHT SIDE

TOP VIEW



SIDE VIEW

L_{LEFT} = 4 5/8 in.

L_{RIGHT} = 5 3/16 in.

A_{LEFT} = 53 °

A_{RIGHT} = 61 1/2°

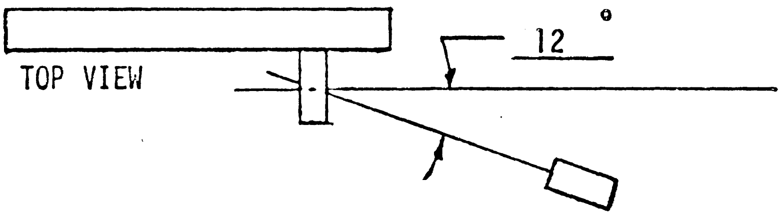
(Sketch indicates Positive Angle directions)

WBR# Certified Dummy

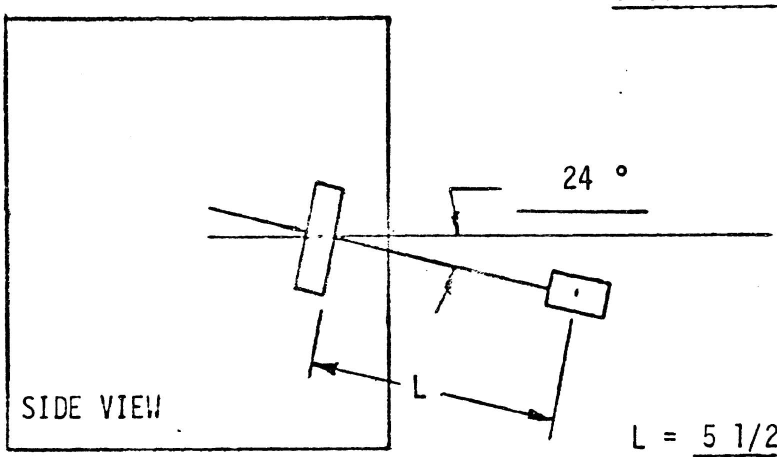
Test No. A-908

WHOLE BODY RESPONSE

BELT ANCHOR ORIENTATIONS

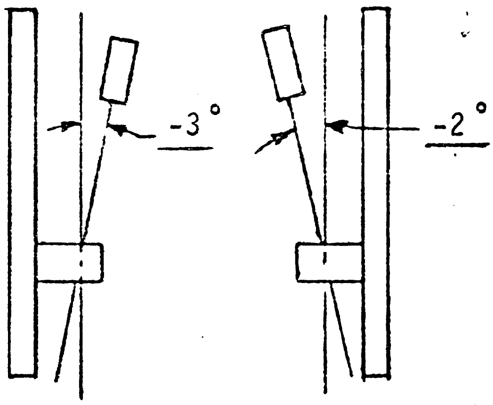


SHOULDER BELT



L = 5 1/2 in.

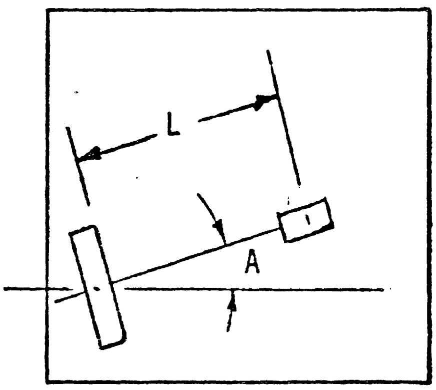
LAP BELT



LEFT SIDE

RIGHT SIDE

TOP VIEW



SIDE VIEW

L_{LEFT} = 5 3/8 in.

L_{RIGHT} = 5 15/16 in.

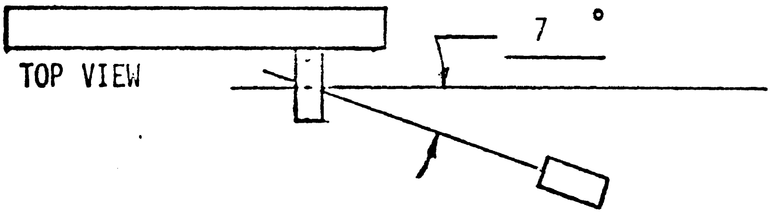
A_{LEFT} = 51 °

A_{RIGHT} = 52 °

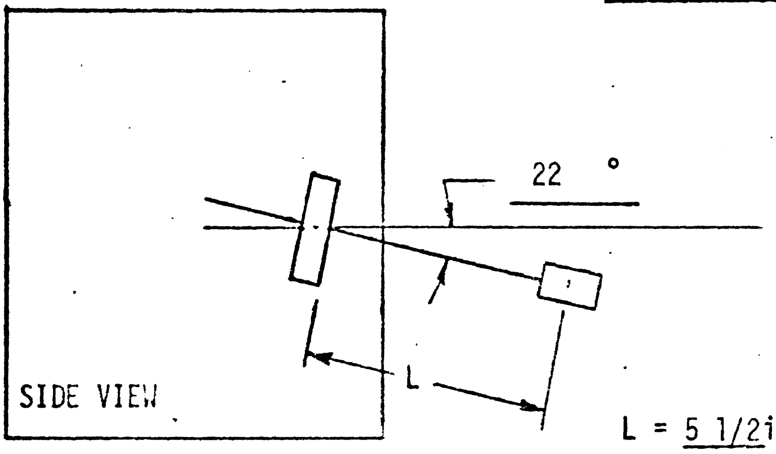
(Sketch indicates Positive Angle directions)

WHOLE BODY RESPONSE

BELT ANCHOR ORIENTATIONS

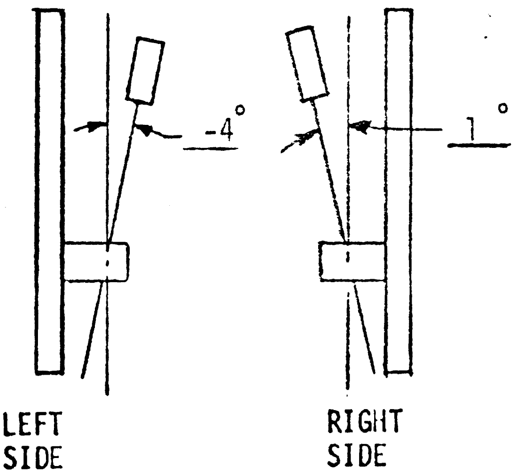


SHOULDER BELT

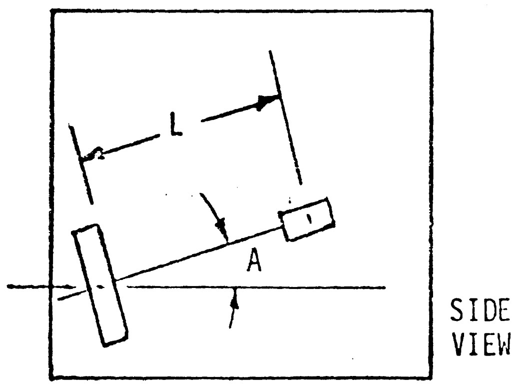


L = 5 1/2in.

LAP BELT



TOP VIEW



L_{LEFT} = 5 1/2 in.

L_{RIGHT} = 5 5/8 in.

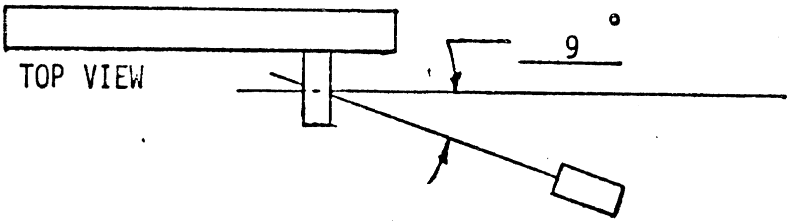
A_{LEFT} = 49 °

A_{RIGHT} = 54 °

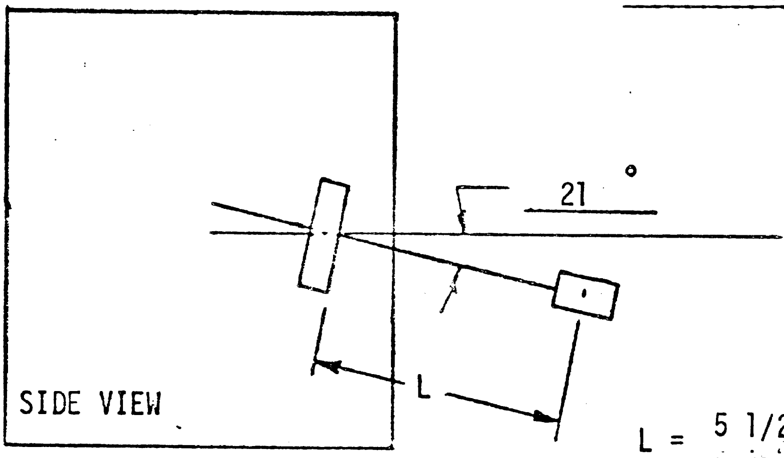
(Sketch indicates Positive Angle directions)

WHOLE BODY RESPONSE

BELT ANCHOR ORIENTATIONS

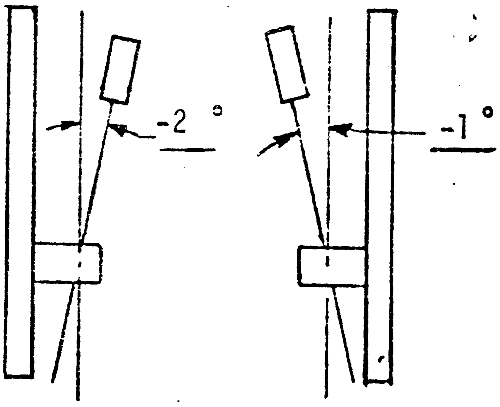


SHOULDER BELT



L = 5 1/2 in

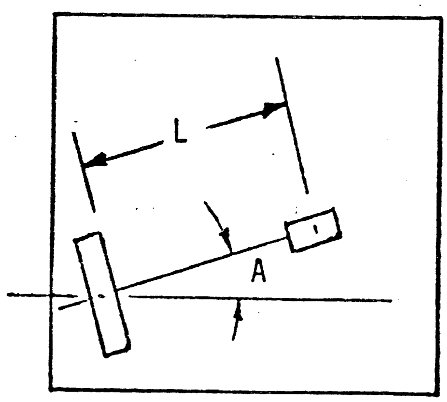
LAP BELT



LEFT SIDE

RIGHT SIDE

TOP VIEW



SIDE VIEW

L_{LEFT} = 5 3/4 in.

L_{RIGHT} = 5 3/4 in.

A_{LEFT} = 49 °

A_{RIGHT} = 53 °

(Sketch indicates Positive Angle directions)

WHOLE BODY RESPONSE WBR# Certified Dummy

BELT LENGTH DATA

TEST A- 907

BELT DATA NOT AVAILABLE

Belt Position	Pre-Impact Length (in)	Post-Impact Length (in)	Belt Stretch (in)	Post-Impact Length with Load Cells
Rt. Lap				
Lt. Lap				
Shoulder				

Test A- 908

Belt Position	Pre-Impact Length (in)	Post-Impact Length (in)	Belt Stretch (in)	Post-Impact Length with Load Cells
Rt. Lap	12	12 1/4	1/4	11 1/2
Lt. Lap	32	32 1/2	0	31 5/8
Shoulder	42	42	0	40 1/2

WHOLE BODY RESPONSE WBR# Certified Dummy

BELT LENGTH DATA

TEST A- 909

Belt Position	Pre-Impact Length (in)	Post-Impact Length (in)	Belt Stretch (in)	Post-Impact Length with Load Cells
Rt. Lap	12	12 1/4	1/4	11 3/8
Lt. Lap	32 1/2	32 1/2	0	31 3/4
Shoulder	42	42	0	40 1/2

Test A- 910

Belt Position	Pre-Impact Length (in)	Post-Impact Length (in)	Belt Stretch (in)	Post-Impact Length with Load Cells
Rt. Lap	12	12	0	11 1/4
Lt. Lap	32 1/2	32 5/8	1/8	31 7/8
Shoulder	42	42	0	40 5/8

TAPE: GMR-F1

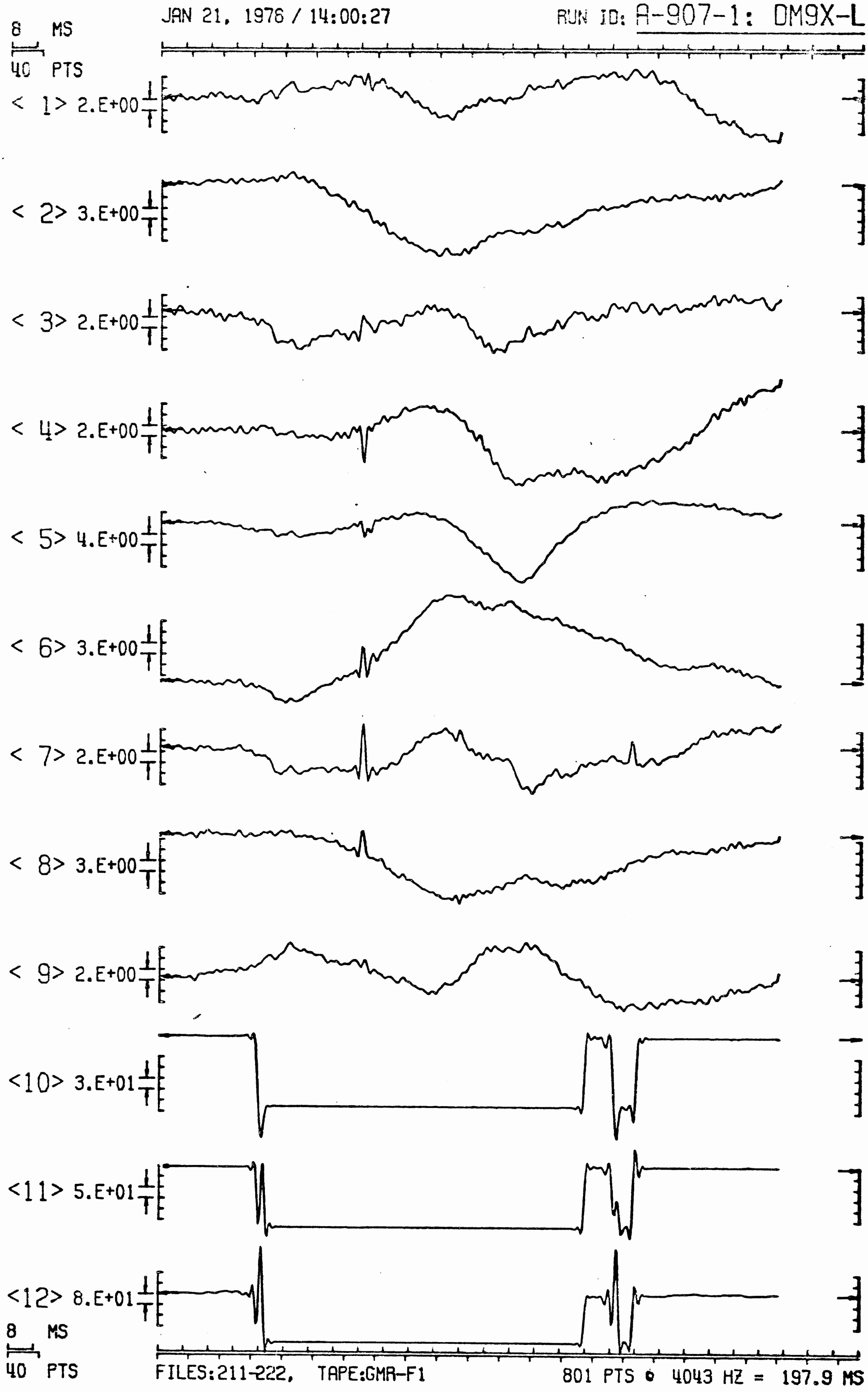
DIGITAL SIGNAL FILTERING
JAN 21, 1976 02:26:03

RUN ID: A-907-1: DM9X-L

PROJECT: WHOLE BODY RESPONSE.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
211 -	1:	ACC-X @ Q1 (HEAD A1)	G'S	801	4043.	LP(090-180)	(3)
212 -	2:	ACC-Y @ Q1 (HEAD B1)	G'S	801	4043.	LP(090-180)	(3)
213 -	3:	ACC-Z @ Q1 (HEAD C1)	G'S	801	4043.	LP(090-180)	(3)
214 -	4:	ACC-X @ Q2 (HEAD C2)	G'S	801	4043.	LP(090-180)	(3)
215 -	5:	ACC-Y @ Q2 (HEAD A2)	G'S	801	4043.	LP(090-180)	(3)
216 -	6:	ACC-Z @ Q2 (HEAD B2)	G'S	801	4043.	LP(090-180)	(3)
217 -	7:	ACC-X @ Q3 (HEAD B3)	G'S	801	4043.	LP(090-180)	(3)
218 -	8:	ACC-Y @ Q3 (HEAD C3)	G'S	801	4043.	LP(090-180)	(3)
219 -	9:	ACC-Z @ Q3 (HEAD A3)	G'S	801	4043.	LP(090-180)	(3)
220 -	10:	HEAD TRIAX A-P ACC	G'S	801	4043.	LP(090-180)	(3)
221 -	11:	HEAD TRIAX S-I ACC	G'S	801	4043.	LP(090-180)	(3)
222 -	12:	HEAD TRIAX L-R ACC	G'S	801	4043.	LP(090-180)	(3)

FILES: 211 - 222 ON TAPE: GMR-F1 RUN: A-907-1: DM9X-L FILTERED JAN 21, 1976 02:26:41


JAN 21, 1976 / 14:00:27
RUN ID: A-907-1: DM9X-L
8 MS
40 PTS
< 1> 2.E+00
< 2> 3.E+00
< 3> 2.E+00
< 4> 2.E+00
< 5> 4.E+00
< 6> 3.E+00
< 7> 2.E+00
< 8> 3.E+00
< 9> 2.E+00
<10> 3.E+01
<11> 5.E+01
<12> 8.E+01
8 MS
40 PTS
FILES:211-222, TAPE:GMR-F1
801 PTS @ 4043 HZ = 197.9 MS

TAPE: GMR-F1

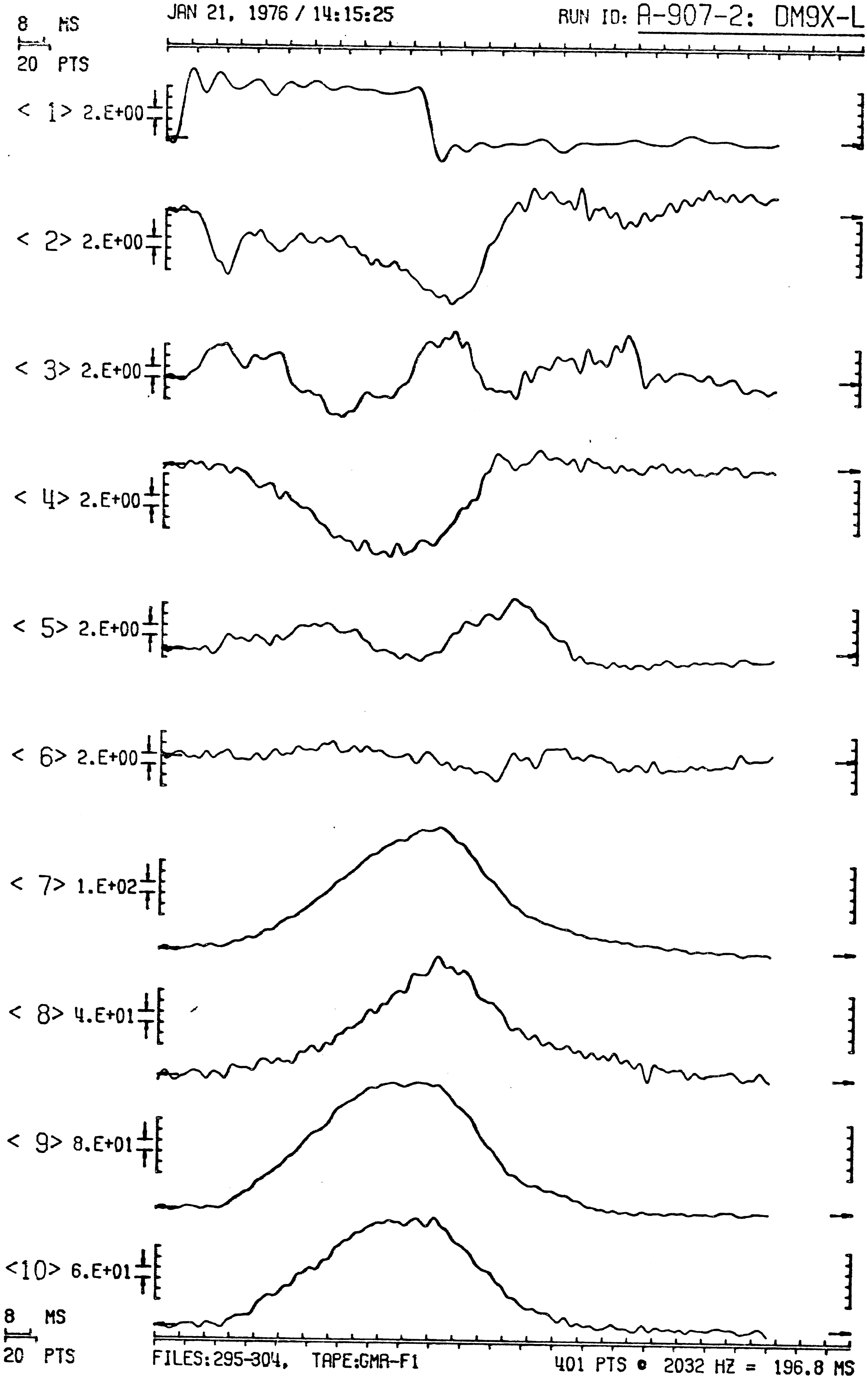
DIGITAL SIGNAL FILTERING
JAN 21, 1976 02:45:02

RUN ID: A-907-2: DM9X-L

PROJECT: WHOLE BODY RESPONSE.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
295 -	1:	SLED DECELERATION	G'S	401	2032.	LP(030-090)	(4)
296 -	2:	PELVIS EXT P-A ACC	G'S	401	2032.	LP(090-225)	(5)
297 -	3:	PELVIS EXT I-S ACC	G'S	401	2032.	LP(090-225)	(5)
298 -	4:	THORAX EXT P-A ACC	G'S	401	2032.	LP(090-225)	(5)
299 -	5:	THORAX EXT I-S ACC	G'S	401	2032.	LP(090-225)	(5)
300 -	6:	THORAX EXT R-L ACC	G'S	401	2032.	LP(090-225)	(5)
301 -	7:	RIGHT LAP BELT LOAD	LBS	401	2032.	LP(090-225)	(5)
302 -	8:	LEFT LAP BELT LOAD	LBS	401	2032.	LP(090-225)	(5)
303 -	9:	UPPER SHOULDER BELT LOAD	LBS	401	2032.	LP(090-225)	(5)
304 -	10:	LOWER SHOULDER BELT LOAD	LBS	401	2032.	LP(090-225)	(5)
	11:						
	12:						

FILES: 295 - 304 ON TAPE: GMR-F1 RUN: A-907-2: DM9X-L FILTERED JAN 21, 1976 02:45:34



JAN 21, 1976 / 14:15:25
RUN ID: A-907-2: DM9X-L
8 MS
20 PTS
< 1> 2.E+00
< 2> 2.E+00
< 3> 2.E+00
< 4> 2.E+00
< 5> 2.E+00
< 6> 2.E+00
< 7> 1.E+02
< 8> 4.E+01
< 9> 8.E+01
<10> 6.E+01
8 MS
20 PTS
FILES:295-304, TAPE:GMR-F1
401 PTS @ 2032 HZ = 196.8 MS

TAPE: GMR-F1

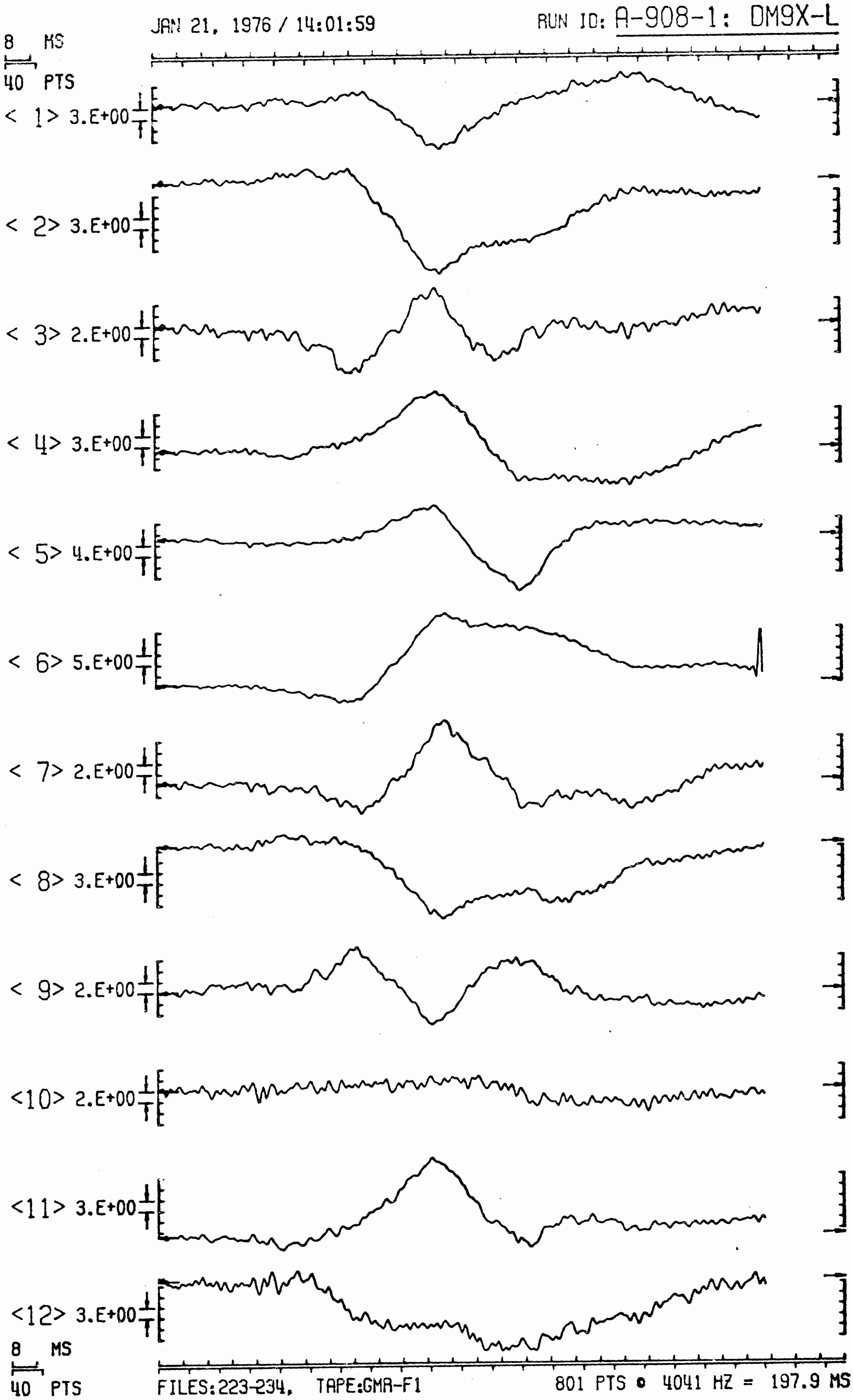
DIGITAL SIGNAL FILTERING
JAN 21, 1976 02:27:46

RUN ID: A-908-1: DM9X-L

PROJECT: WHOLE BODY RESPONSE.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
223 -	1:	ACC-X @ Q1 (HEAD A1)	G'S	801	4042.	LP(090-180)	(3)
224 -	2:	ACC-Y @ Q1 (HEAD B1)	G'S	801	4042.	LP(090-180)	(3)
225 -	3:	ACC-Z @ Q1 (HEAD C1)	G'S	801	4042.	LP(090-180)	(3)
226 -	4:	ACC-X @ Q2 (HEAD C2)	G'S	801	4042.	LP(090-180)	(3)
227 -	5:	ACC-Y @ Q2 (HEAD A2)	G'S	801	4042.	LP(090-180)	(3)
228 -	6:	ACC-Z @ Q2 (HEAD B2)	G'S	801	4042.	LP(090-180)	(3)
229 -	7:	ACC-X @ Q3 (HEAD B3)	G'S	801	4042.	LP(090-180)	(3)
230 -	8:	ACC-Y @ Q3 (HEAD C3)	G'S	801	4042.	LP(090-180)	(3)
231 -	9:	ACC-Z @ Q3 (HEAD A3)	G'S	801	4042.	LP(090-180)	(3)
232 -	10:	HEAD TRIAX A-P ACC	G'S	801	4042.	LP(090-180)	(3)
233 -	11:	HEAD TRIAX S-I ACC	G'S	801	4042.	LP(090-180)	(3)
234 -	12:	HEAD TRIAX L-R ACC	G'S	801	4042.	LP(090-180)	(3)

FILES: 223 - 234 ON TAPE: GMR-F1 RUN: A-908-1: DM9X-L FILTERED JAN 21, 1976 02:28:24


JAN 21, 1976 / 14:01:59
RUN ID: A-908-1: DM9X-L
8 MS
40 PTS
< 1> 3.E+00
< 2> 3.E+00
< 3> 2.E+00
< 4> 3.E+00
< 5> 4.E+00
< 6> 5.E+00
< 7> 2.E+00
< 8> 3.E+00
< 9> 2.E+00
<10> 2.E+00
<11> 3.E+00
<12> 3.E+00
8 MS
40 PTS
FILES:223-234, TAPE:GMA-F1
801 PTS @ 4041 HZ = 197.9 MS

TAPE: GMR-F1

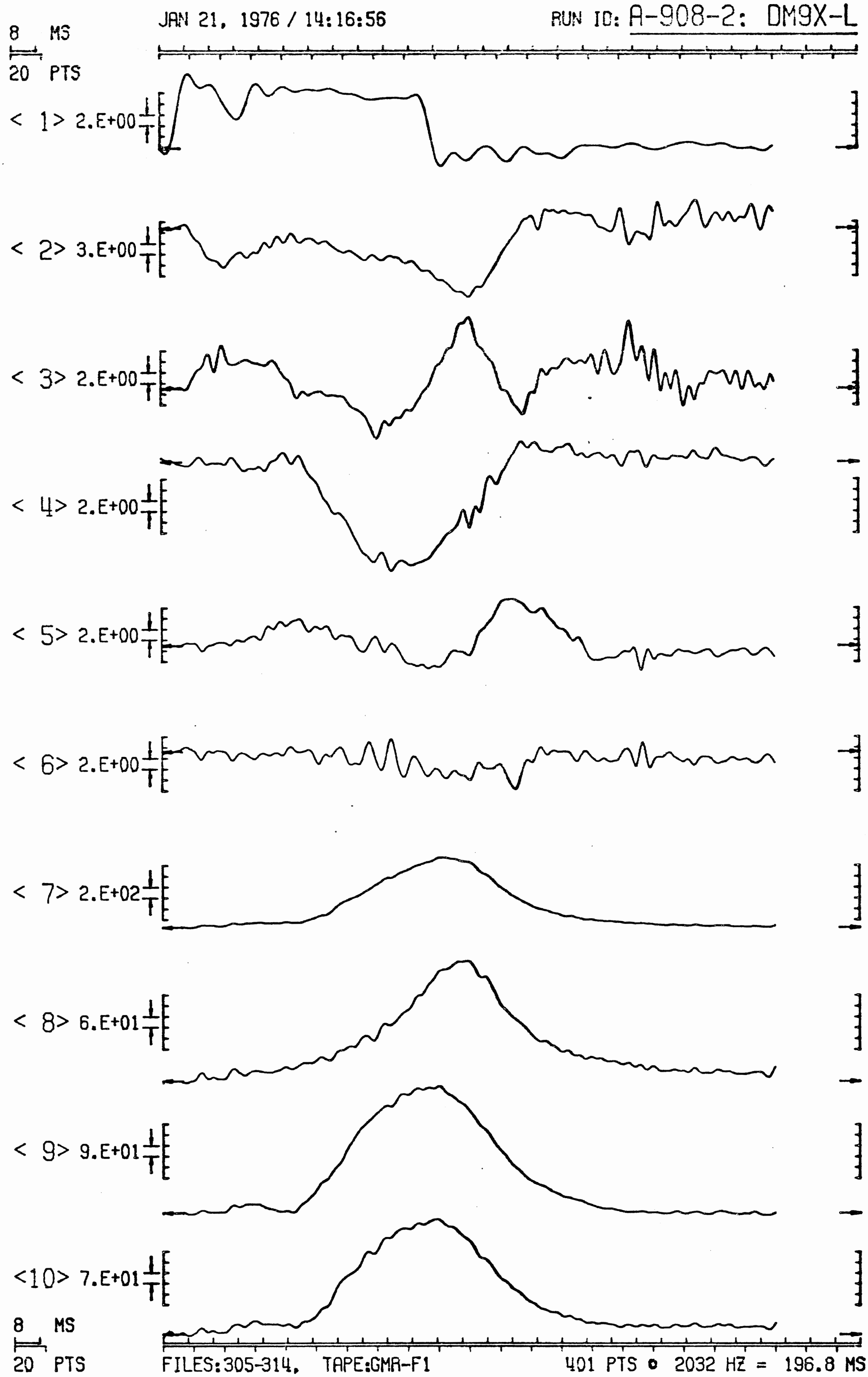
DIGITAL SIGNAL FILTERING
JAN 21, 1976 02:46:38

RUN ID: A-908-2: DM9X-L

PROJECT: WHOLE BODY RESPONSE.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
305 -	1:	SLED DECELERATION	G'S	401	2032.	LP(030-090)	(4)
306 -	2:	PELVIS EXT P-A ACC	G'S	401	2032.	LP(090-225)	(5)
307 -	3:	PELVIS EXT I-S ACC	G'S	401	2032.	LP(090-225)	(5)
308 -	4:	THORAX EXT P-A ACC	G'S	401	2032.	LP(090-225)	(5)
309 -	5:	THORAX EXT I-S ACC	G'S	401	2032.	LP(090-225)	(5)
310 -	6:	THORAX EXT R-L ACC	G'S	401	2032.	LP(090-225)	(5)
311 -	7:	RIGHT LAP BELT LOAD	LBS	401	2032.	LP(090-225)	(5)
312 -	8:	LEFT LAP BELT LOAD	LBS	401	2032.	LP(090-225)	(5)
313 -	9:	UPPER SHOULDER BELT LOAD	LBS	401	2032.	LP(090-225)	(5)
314 -	10:	LOWER SHOULDER BELT LOAD	LBS	401	2032.	LP(090-225)	(5)
	11:						
	12:						

FILES: 305 - 314 ON TAPE: GMR-F1 RUN: A-908-2: DM9X-L FILTERED JAN 21, 1976 02:47:11


JAN 21, 1976 / 14:16:56
RUN ID: A-908-2: DM9X-L
8 MS
20 PTS
< 1> 2.E+00
< 2> 3.E+00
< 3> 2.E+00
< 4> 2.E+00
< 5> 2.E+00
< 6> 2.E+00
< 7> 2.E+02
< 8> 6.E+01
< 9> 9.E+01
<10> 7.E+01
8 MS
20 PTS
FILES:305-314, TAPE:GMA-F1
401 PTS @ 2032 HZ = 196.8 MS

TAPE: GMR-F1

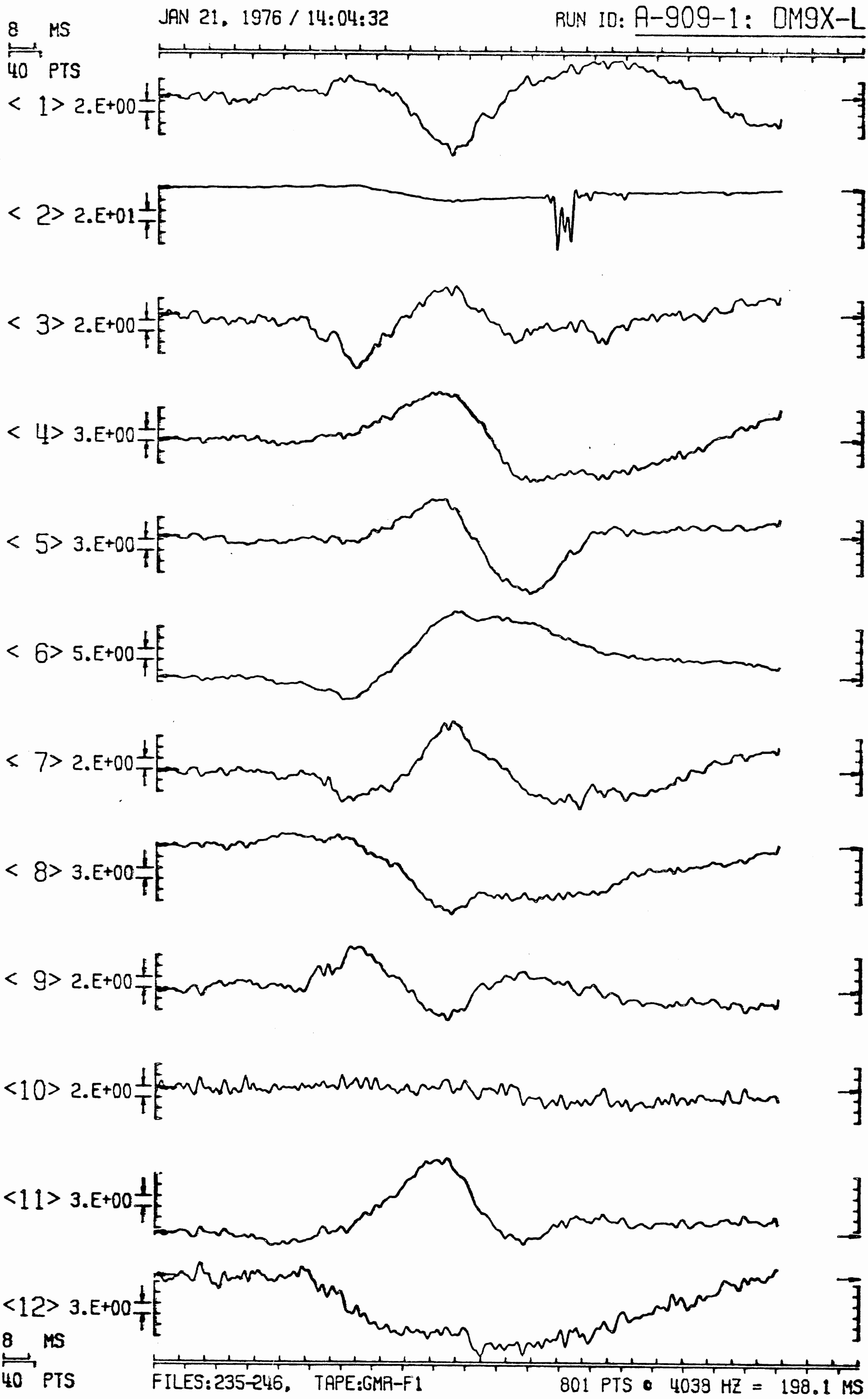
DIGITAL SIGNAL FILTERING
JAN 21, 1976 02:29:28

RUN ID: A-909-1: DM9X-L

PROJECT: WHOLE BODY RESPONSE.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
235 -	1:	ACC-X @ Q1 (HEAD A1)	G'S	801	4039.	LP(090-180)	(3)
236 -	2:	ACC-Y @ Q1 (HEAD B1)	G'S	801	4039.	LP(090-180)	(3)
237 -	3:	ACC-Z @ Q1 (HEAD C1)	G'S	801	4039.	LP(090-180)	(3)
238 -	4:	ACC-X @ Q2 (HEAD C2)	G'S	801	4039.	LP(090-180)	(3)
239 -	5:	ACC-Y @ Q2 (HEAD A2)	G'S	801	4039.	LP(090-180)	(3)
240 -	6:	ACC-Z @ Q2 (HEAD B2)	G'S	801	4039.	LP(090-180)	(3)
241 -	7:	ACC-X @ Q3 (HEAD B3)	G'S	801	4039.	LP(090-180)	(3)
242 -	8:	ACC-Y @ Q3 (HEAD C3)	G'S	801	4039.	LP(090-180)	(3)
243 -	9:	ACC-Z @ Q3 (HEAD A3)	G'S	801	4039.	LP(090-180)	(3)
244 -	10:	HEAD TRIAX A-P ACC	G'S	801	4039.	LP(090-180)	(3)
245 -	11:	HEAD TRIAX S-I ACC	G'S	801	4039.	LP(090-180)	(3)
246 -	12:	HEAD TRIAX L-R ACC	G'S	801	4039.	LP(090-180)	(3)

FILES: 235 - 246 ON TAPE: GMR-F1 RUN: A-909-1: DM9X-L FILTERED JAN 21, 1976 02:30:05


JAN 21, 1976 / 14:04:32
RUN ID: A-909-1: DM9X-L
8 MS
40 PTS
< 1> 2.E+00
< 2> 2.E+01
< 3> 2.E+00
< 4> 3.E+00
< 5> 3.E+00
< 6> 5.E+00
< 7> 2.E+00
< 8> 3.E+00
< 9> 2.E+00
<10> 2.E+00
<11> 3.E+00
<12> 3.E+00
8 MS
40 PTS
FILES:235-246, TAPE:GMA-F1
801 PTS @ 4038 HZ = 198.1 MS

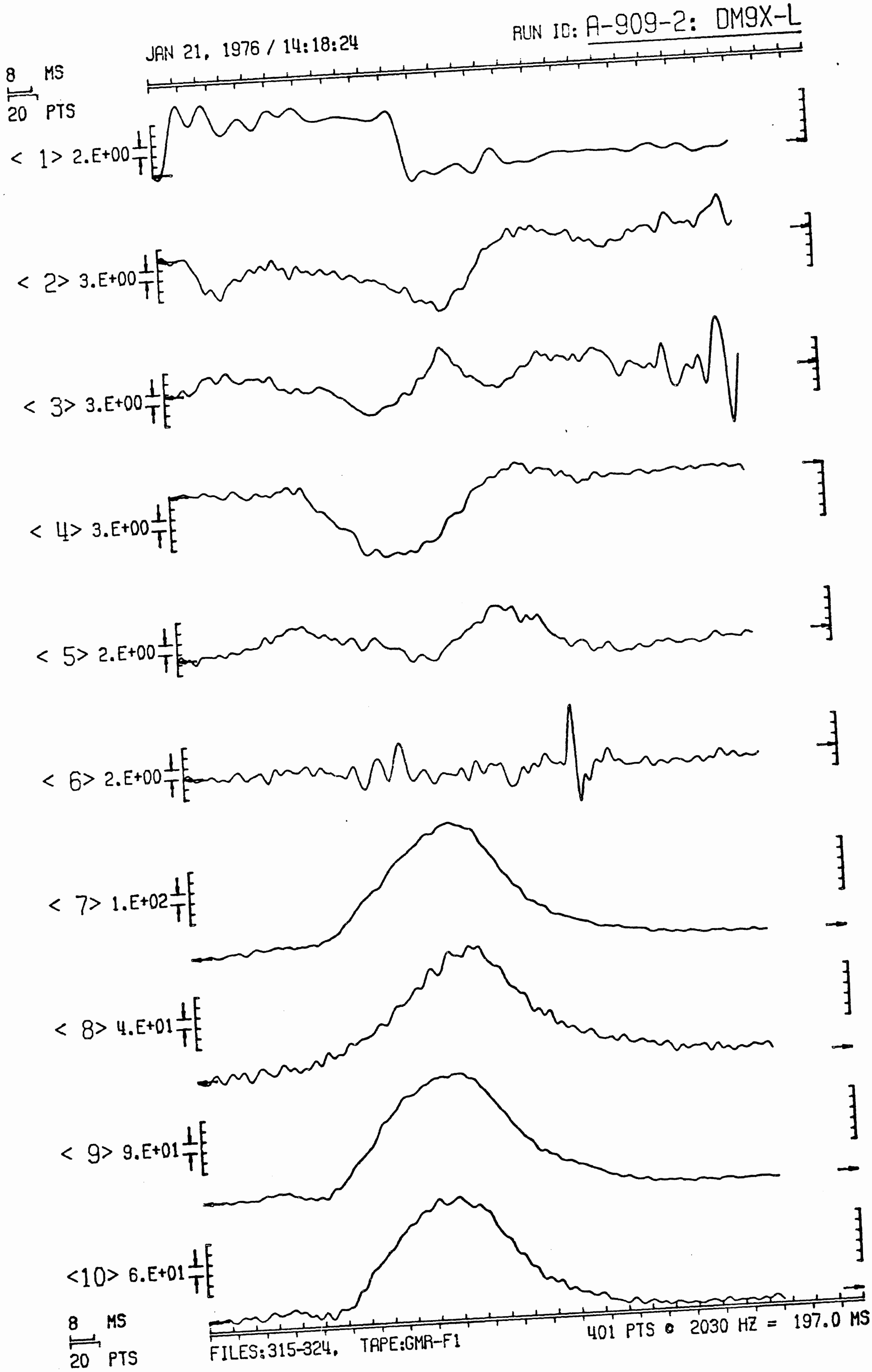
DIGITAL SIGNAL FILTERING

TAPE: GMR-F1 JAN 21, 1976 02:48:13 RUN ID: A-909-2: DM9X-L

PROJECT: WHOLE BODY RESPONSE.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
315 -	1:	SLED DECELERATION	G'S	401	2031.	LP(030-090)	(4)
316 -	2:	PELVIS EXT P-A ACC	G'S	401	2031.	LP(090-225)	(5)
317 -	3:	PELVIS EXT I-S ACC	G'S	401	2031.	LP(090-225)	(5)
318 -	4:	THORAX EXT P-A ACC	G'S	401	2031.	LP(090-225)	(5)
319 -	5:	THORAX EXT I-S ACC	G'S	401	2031.	LP(090-225)	(5)
320 -	6:	THORAX EXT R-L ACC	G'S	401	2031.	LP(090-225)	(5)
321 -	7:	RIGHT LAP BELT LOAD	LBS	401	2031.	LP(090-225)	(5)
322 -	8:	LEFT LAP BELT LOAD	LBS	401	2031.	LP(090-225)	(5)
323 -	9:	UPPER SHOULDER BELT LOAD	LBS	401	2031.	LP(090-225)	(5)
324 -	10:	LOWER SHOULDER BELT LOAD	LBS	401	2031.	LP(090-225)	(5)
	11:						
	12:						

FILES: 315 - 324 ON TAPE: GMR-F1 RUN: A-909-2: DM9X-L FILTERED JAN 21, 1976 02:48:46


JAN 21, 1976 / 14:18:24
RUN ID: A-909-2: DM9X-L
8 MS
20 PTS
< 1> 2.E+00
< 2> 3.E+00
< 3> 3.E+00
< 4> 3.E+00
< 5> 2.E+00
< 6> 2.E+00
< 7> 1.E+02
< 8> 4.E+01
< 9> 9.E+01
<10> 6.E+01
8 MS
20 PTS
FILES:315-324, TAPE:GMR-F1
401 PTS @ 2030 HZ = 197.0 MS

TAPE: GMR-F1

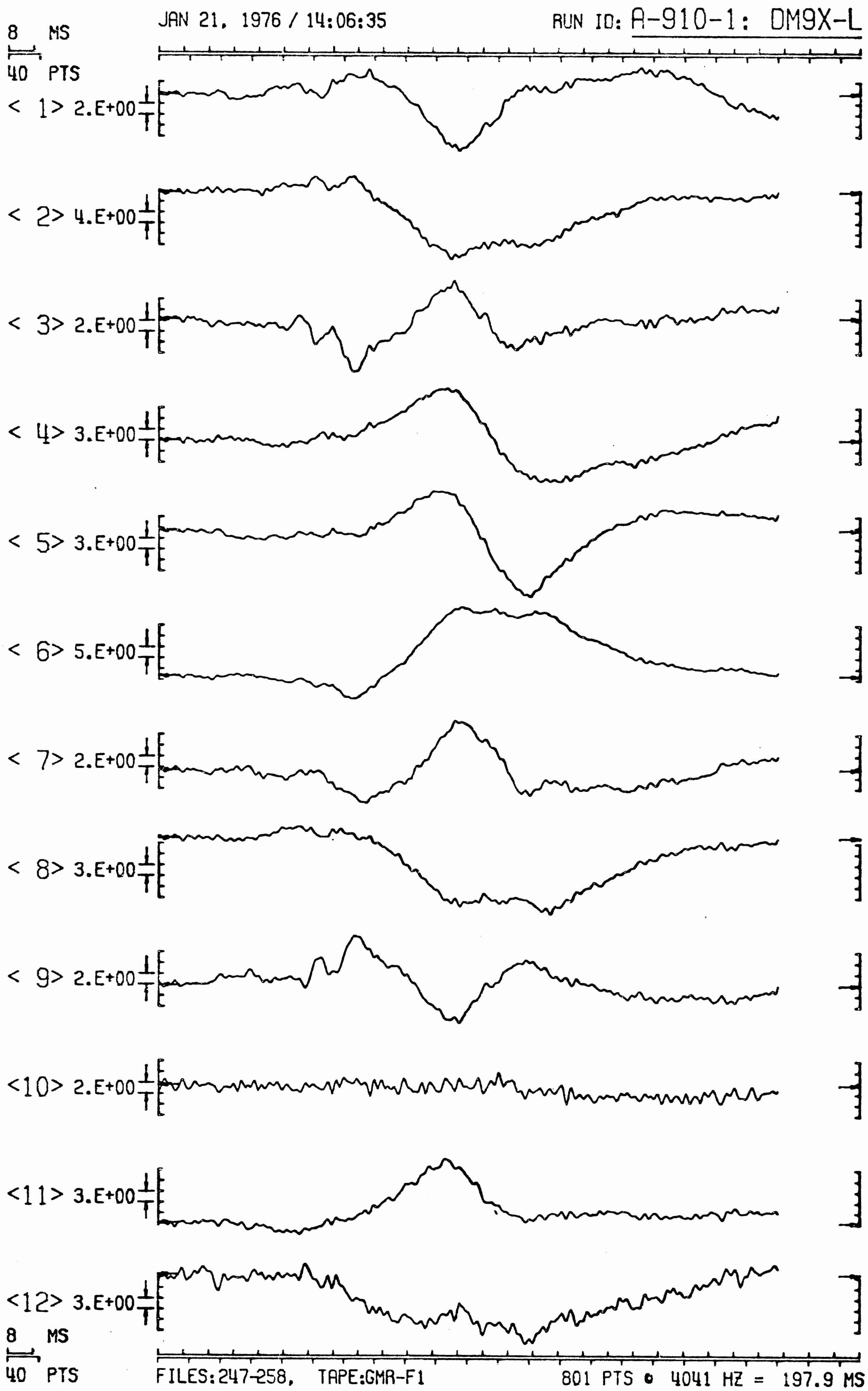
DIGITAL SIGNAL FILTERING
JAN 21, 1976 02:31:13

RUN ID: A-910-1: DM9X-L

PROJECT: WHOLE BODY RESPONSE.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
247 -	1:	ACC-X @ Q1 (HEAD A1)	G'S	801	4041.	LP(090-180)	(3)
248 -	2:	ACC-Y @ Q1 (HEAD B1)	G'S	801	4041.	LP(090-180)	(3)
249 -	3:	ACC-Z @ Q1 (HEAD C1)	G'S	801	4041.	LP(090-180)	(3)
250 -	4:	ACC-X @ Q2 (HEAD C2)	G'S	801	4041.	LP(090-180)	(3)
251 -	5:	ACC-Y @ Q2 (HEAD A2)	G'S	801	4041.	LP(090-180)	(3)
252 -	6:	ACC-Z @ Q2 (HEAD B2)	G'S	801	4041.	LP(090-180)	(3)
253 -	7:	ACC-X @ Q3 (HEAD B3)	G'S	801	4041.	LP(090-180)	(3)
254 -	8:	ACC-Y @ Q3 (HEAD C3)	G'S	801	4041.	LP(090-180)	(3)
255 -	9:	ACC-Z @ Q3 (HEAD A3)	G'S	801	4041.	LP(090-180)	(3)
256 -	10:	HEAD TRIAX A-P ACC	G'S	801	4041.	LP(090-180)	(3)
257 -	11:	HEAD TRIAX S-I ACC	G'S	801	4041.	LP(090-180)	(3)
258 -	12:	HEAD TRIAX L-R ACC	G'S	801	4041.	LP(090-180)	(3)

FILES: 247 - 258 ON TAPE: GMR-F1 RUN: A-910-1: DM9X-L FILTERED JAN 21, 1976 02:31:51


JAN 21, 1976 / 14:06:35
RUN ID: A-910-1: DM9X-L
8 MS
40 PTS
< 1> 2.E+00
< 2> 4.E+00
< 3> 2.E+00
< 4> 3.E+00
< 5> 3.E+00
< 6> 5.E+00
< 7> 2.E+00
< 8> 3.E+00
< 9> 2.E+00
<10> 2.E+00
<11> 3.E+00
<12> 3.E+00
8 MS
40 PTS
FILES:247-258, TAPE:GMR-F1
801 PTS @ 4041 HZ = 197.9 MS

TAPE: GMR-F1

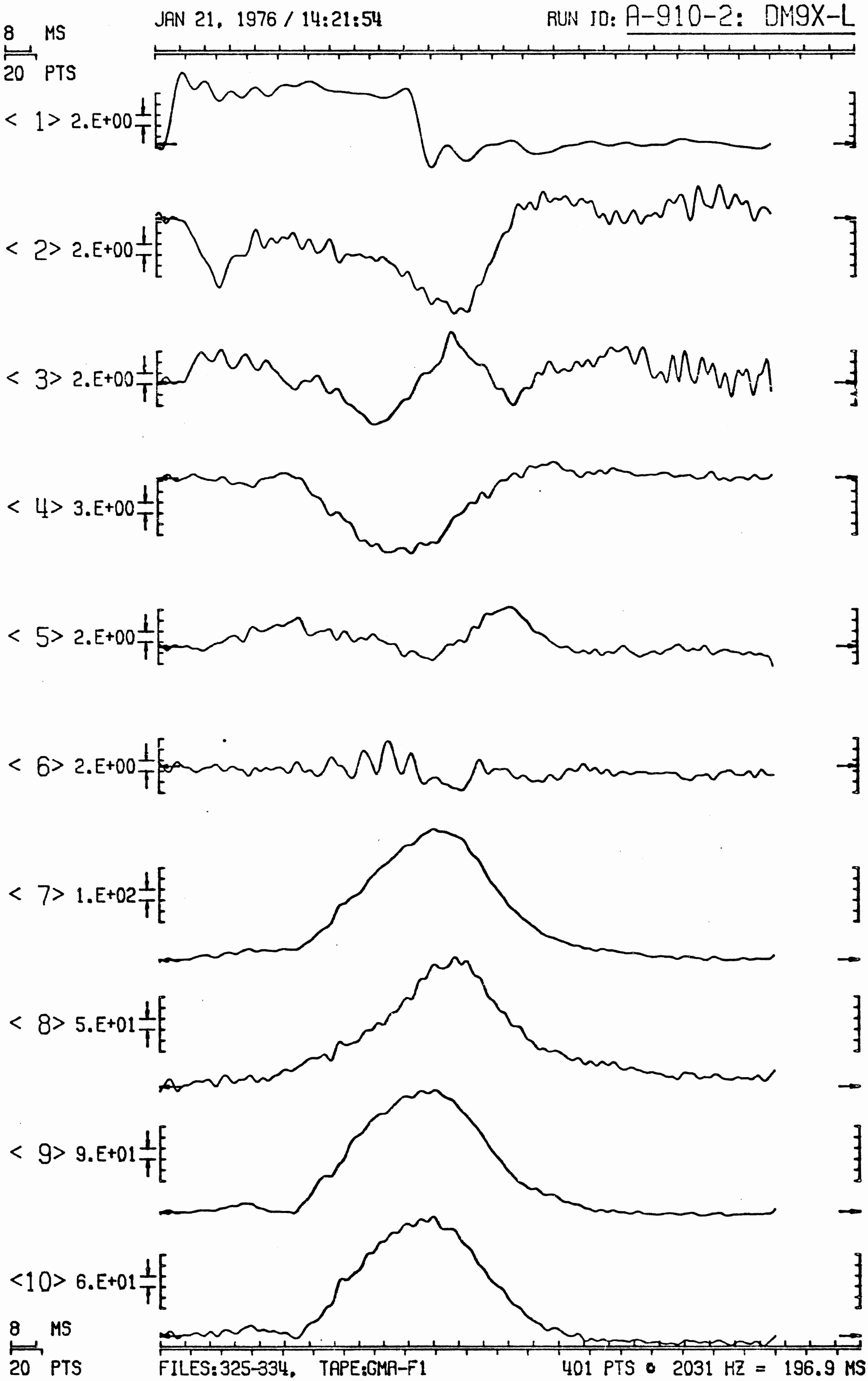
DIGITAL SIGNAL FILTERING
JAN 21, 1976 02:49:59

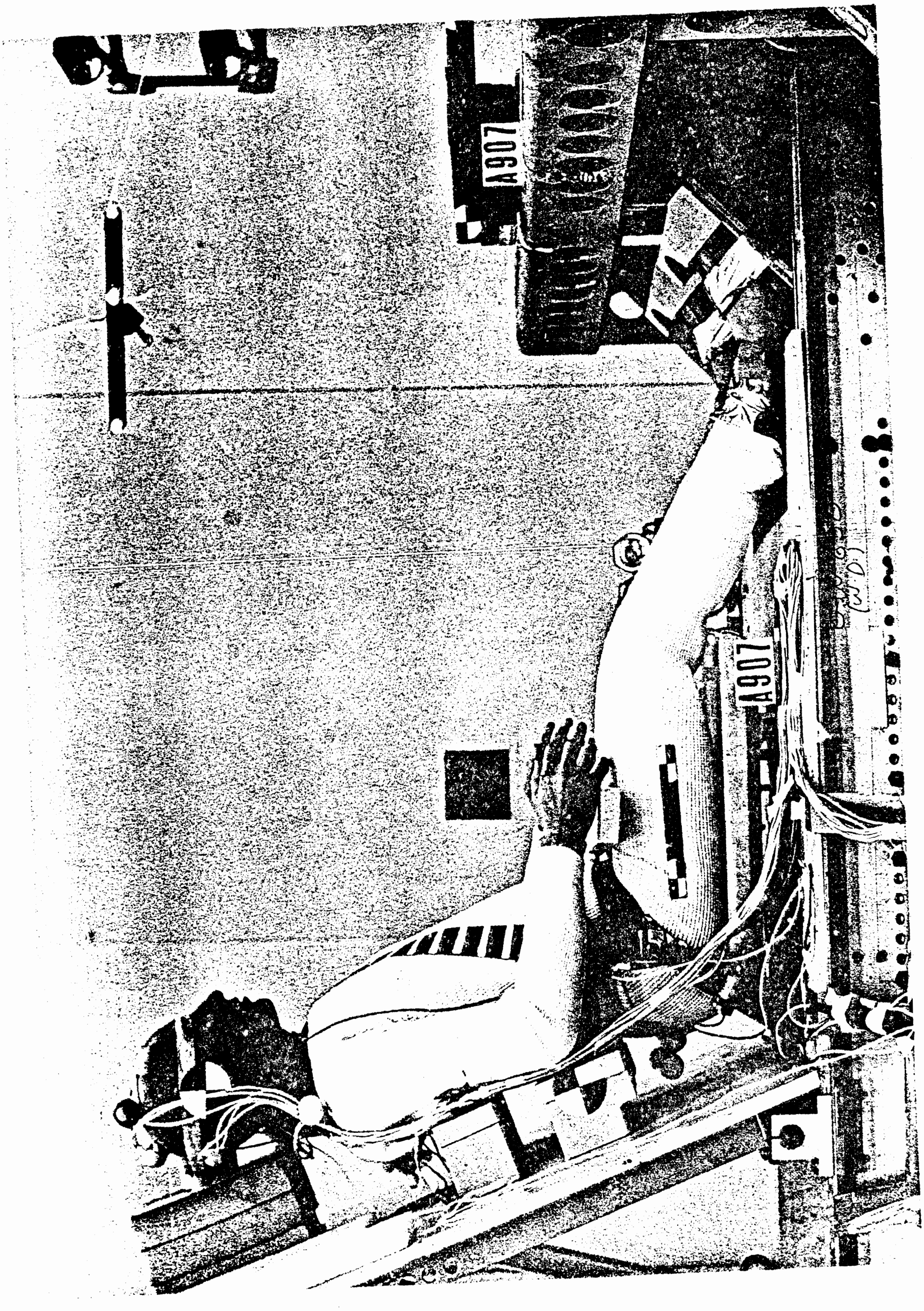
RUN ID: A-910-2: DM9X-L

PROJECT: WHOLE BODY RESPONSE.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
325 -	1:	SLED DECELERATION	G'S	401	2032.	LP(030-090)	(4)
326 -	2:	PELVIS EXT P-A ACC	G'S	401	2032.	LP(090-225)	(5)
327 -	3:	PELVIS EXT I-S ACC	G'S	401	2032.	LP(090-225)	(5)
328 -	4:	THORAX EXT P-A ACC	G'S	401	2032.	LP(090-225)	(5)
329 -	5:	THORAX EXT I-S ACC	G'S	401	2032.	LP(090-225)	(5)
330 -	6:	THORAX EXT R-L ACC	G'S	401	2032.	LP(090-225)	(5)
331 -	7:	RIGHT LAP BELT LOAD	LBS	401	2032.	LP(090-225)	(5)
332 -	8:	LEFT LAP BELT LOAD	LBS	401	2032.	LP(090-225)	(5)
333 -	9:	UPPER SHOULDER BELT LOAD	LBS	401	2032.	LP(090-225)	(5)
334 -	10:	LOWER SHOULDER BELT LOAD	LBS	401	2032.	LP(090-225)	(5)
	11:						
	12:						

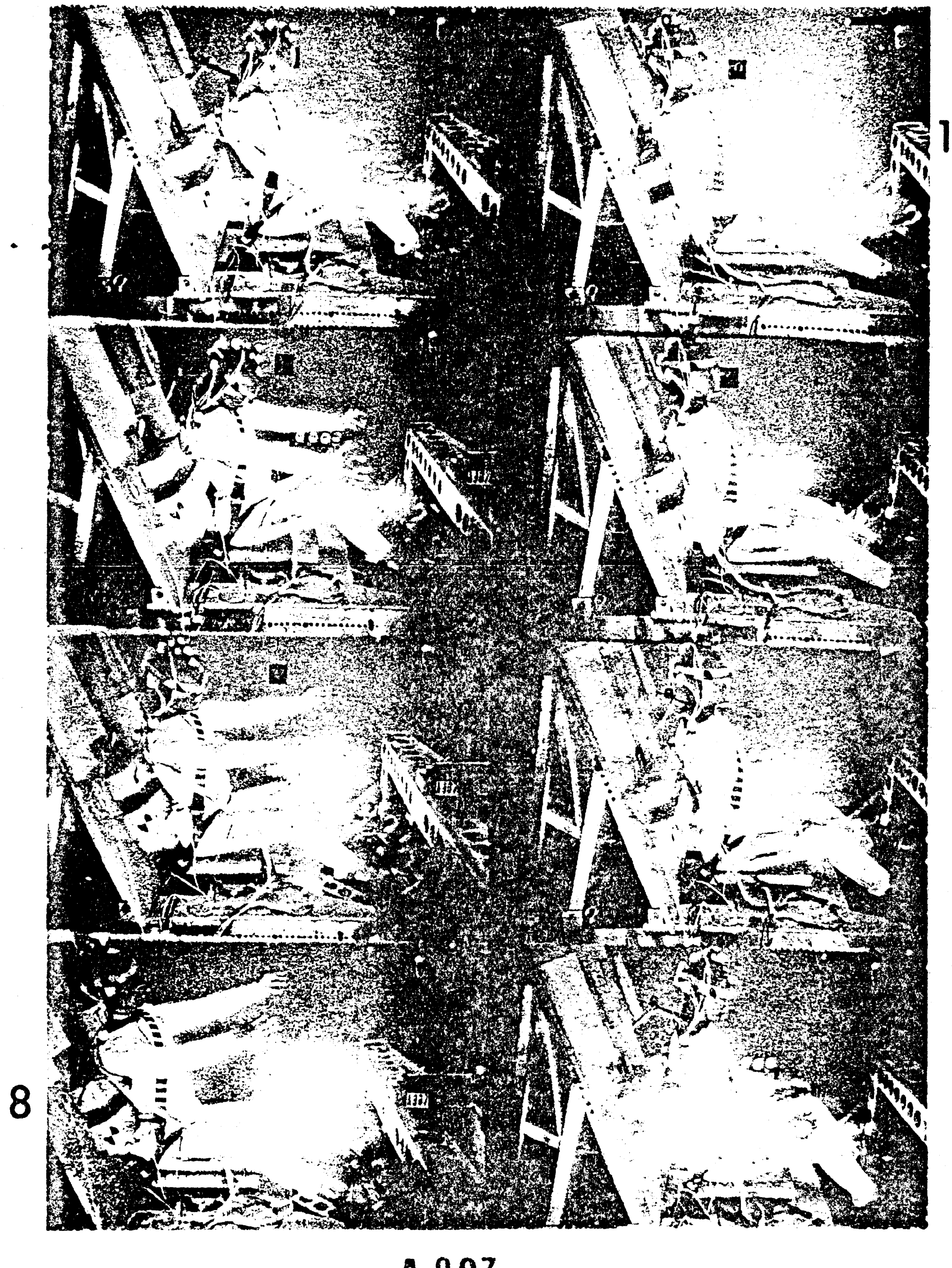
FILES: 325 - 334 ON TAPE: GMR-F1 RUN: A-910-2: DM9X-L FILTERED JAN 21, 1976 02:50:32


JAN 21, 1976 / 14:21:54
RUN ID: A-910-2: DM9X-L
8 MS
20 PTS
< 1> 2.E+00
< 2> 2.E+00
< 3> 2.E+00
< 4> 3.E+00
< 5> 2.E+00
< 6> 2.E+00
< 7> 1.E+02
< 8> 5.E+01
< 9> 9.E+01
<10> 6.E+01
8 MS
20 PTS
FILES:325-334, TAPE:GMA-F1
401 PTS @ 2031 HZ = 196.9 MS

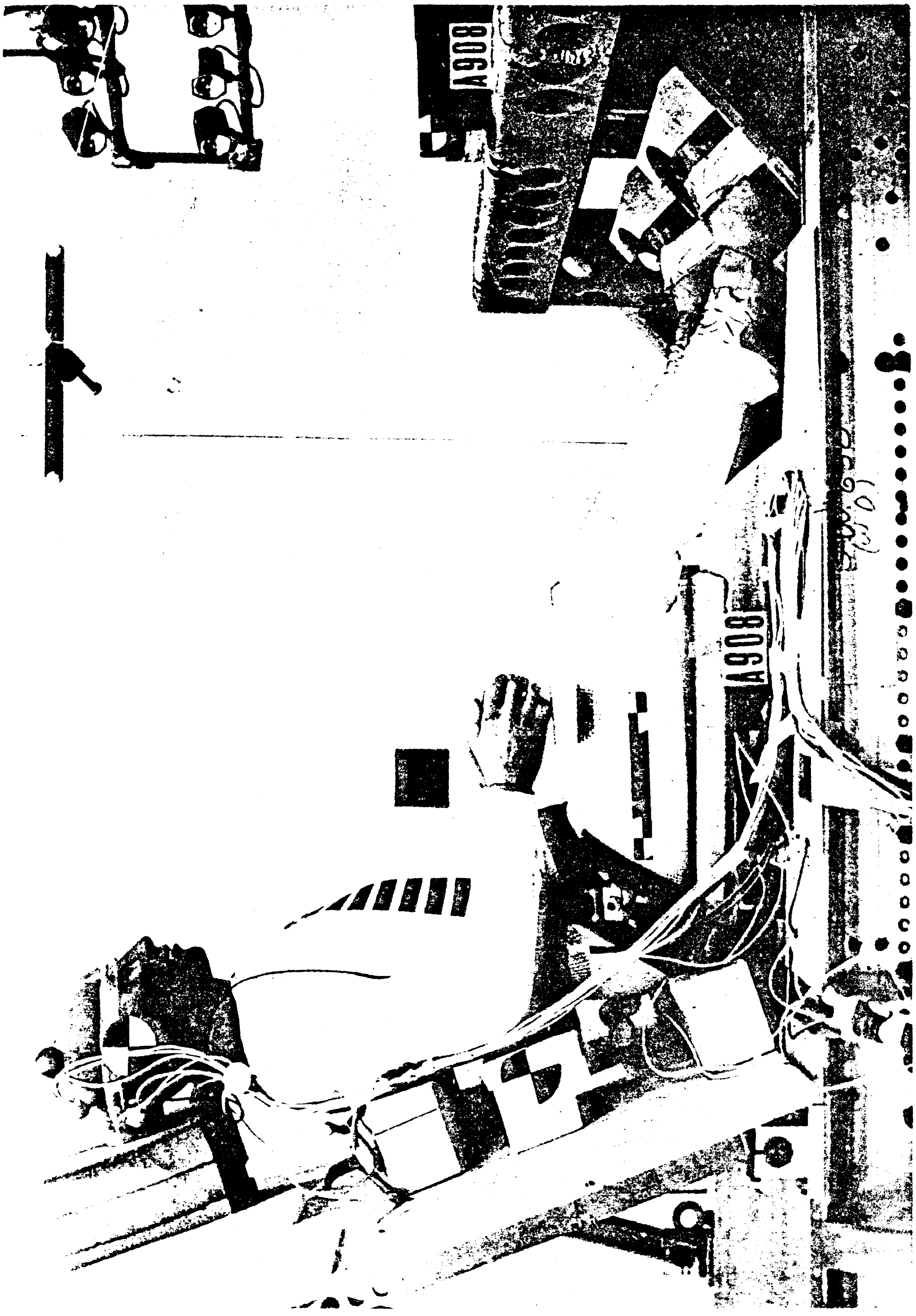


SETUP PHOTOGRAPH: TEST A-907

SETUP PHOTOGRAPH: TEST A-907

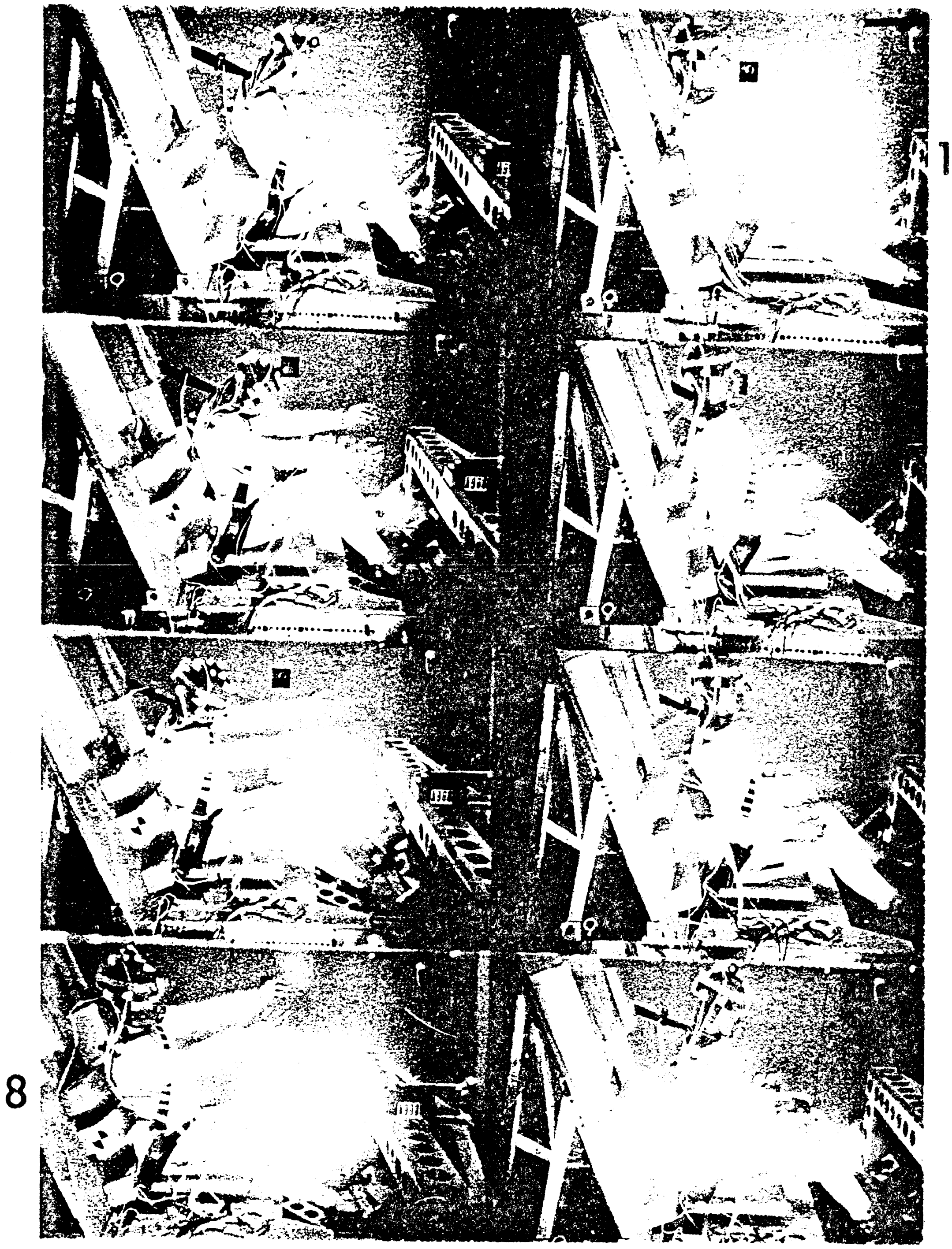


GRAPHCHECK PHOTOGRAPH: TEST A-907



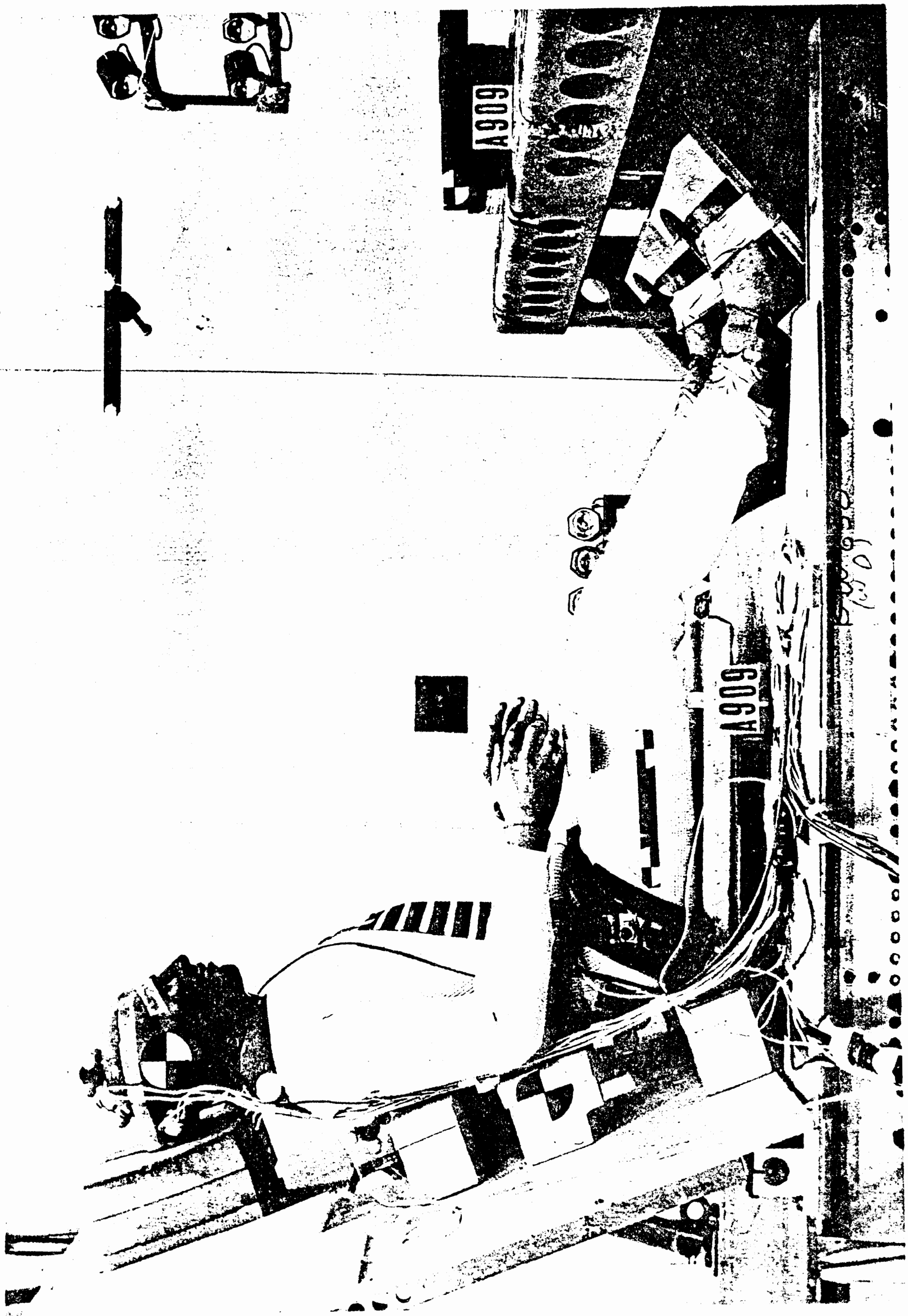
SETUP PHOTOGRAPH: TEST A-908

SETUP PHOTOGRAPH: TEST A-908



A 908

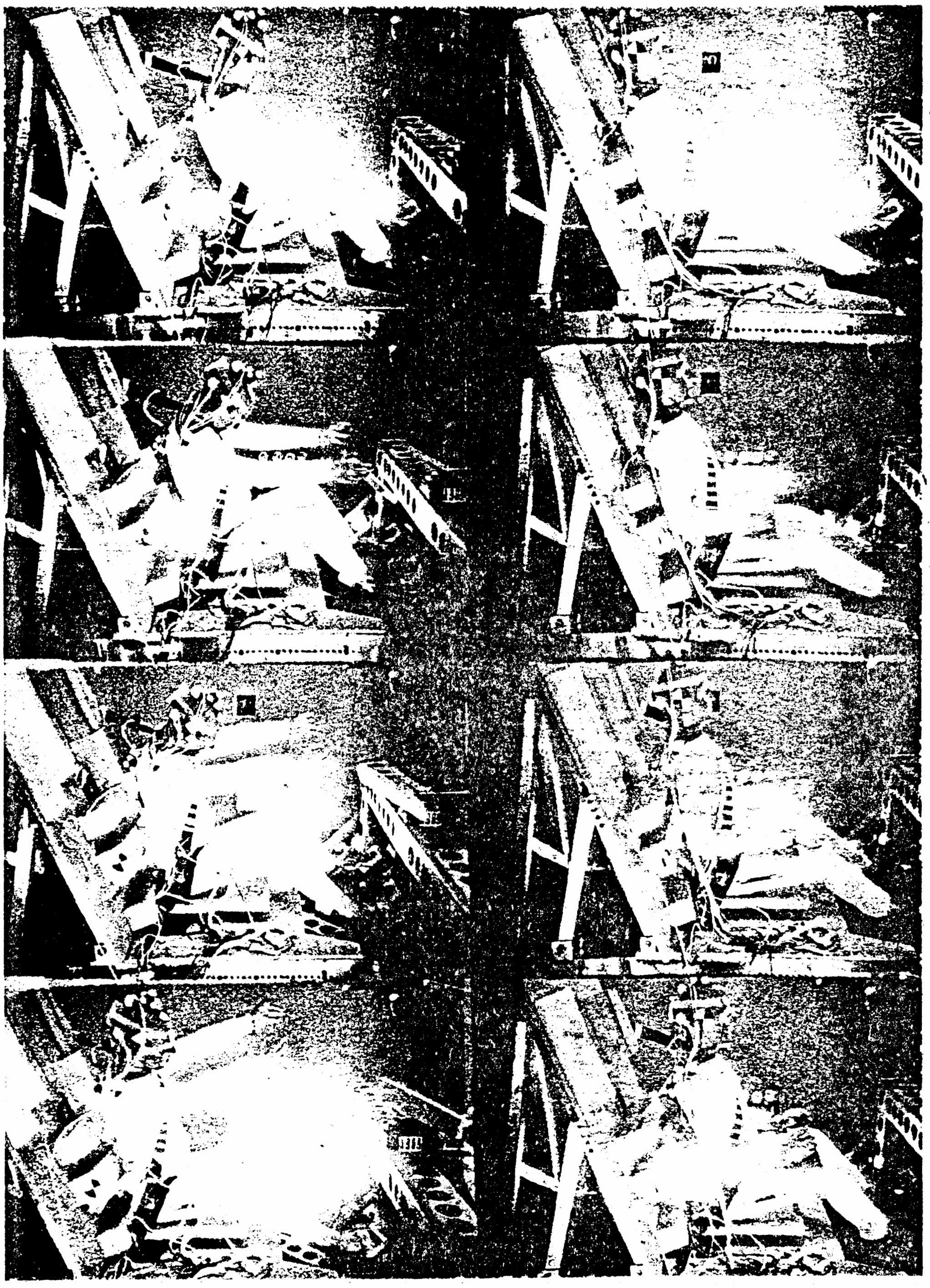
GRAPHCHECK PHOTOGRAPH: TEST A-908



SETUP PHOTOGRAPH: TEST A-909

SETUP PHOTOGRAPH: TEST A-909

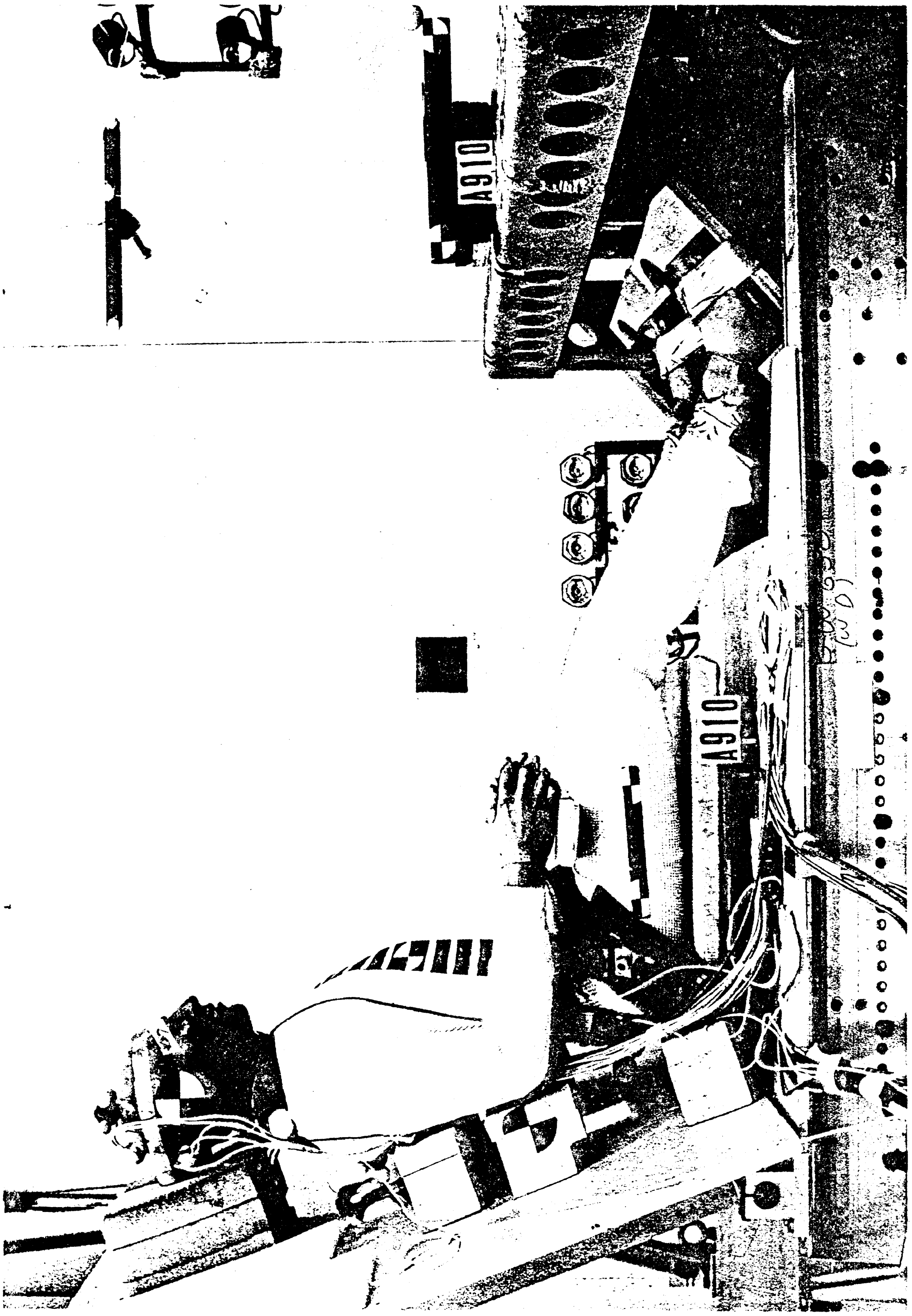
1



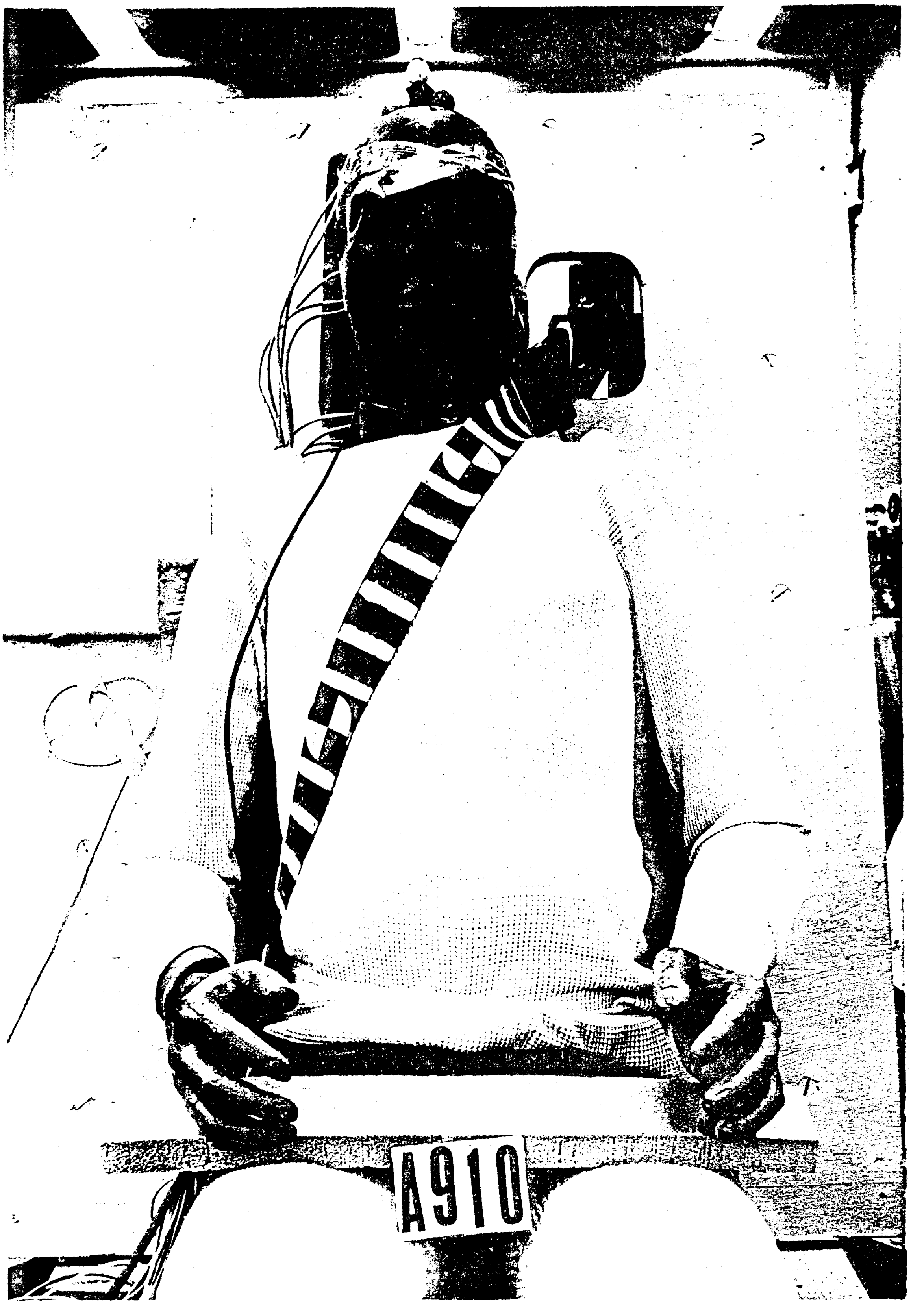
8

A 909

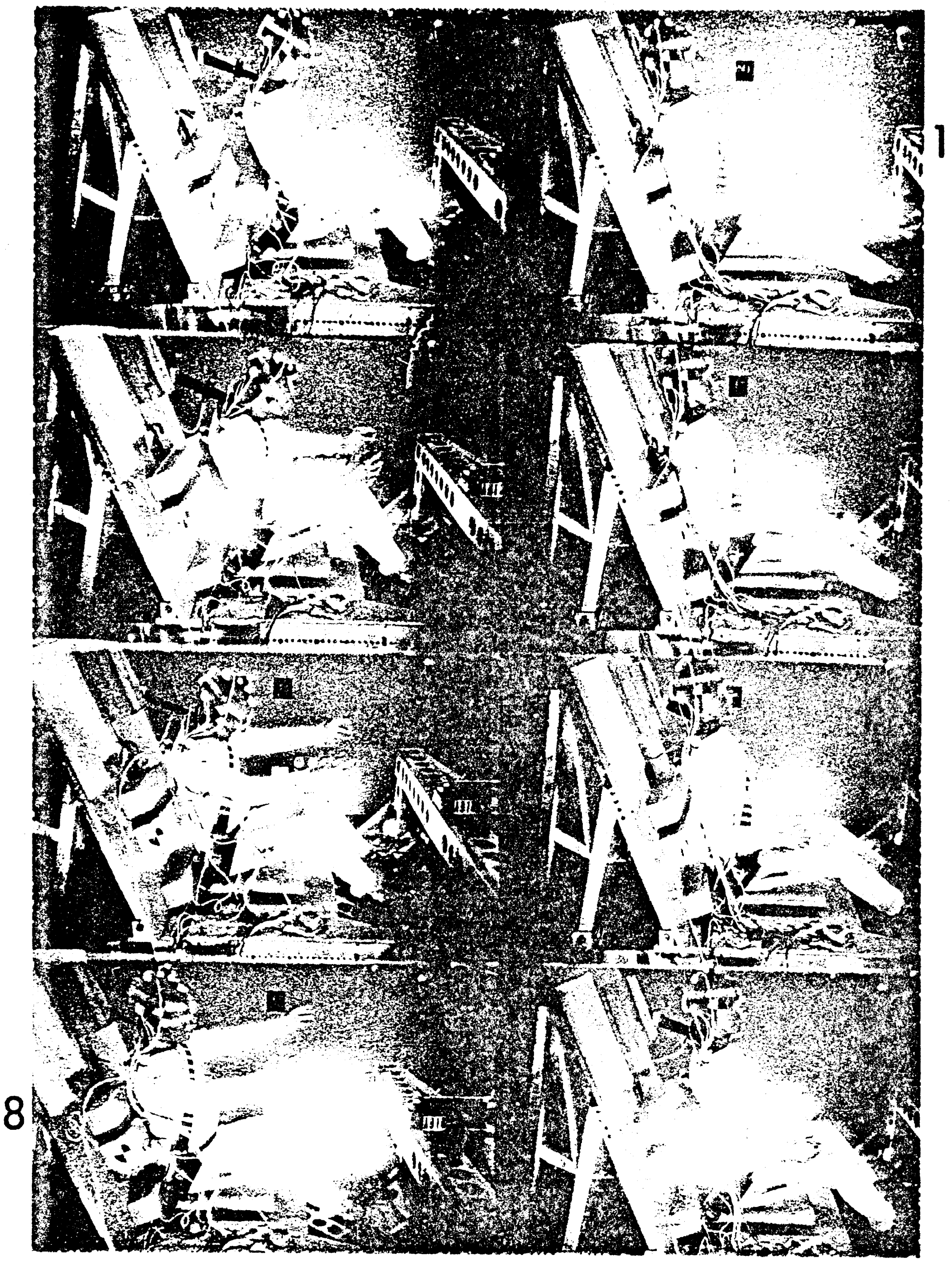
GRAPHCHECK PHOTOGRAPH: TEST A-909



SETUP PHOTOGRAPH: TEST A-910



SETUP PHOTOGRAPH: TEST A-910



A 910

GRAPHCHECK PHOTOGRAPH: TEST A-910

WHOLE BODY RESPONSE

CERTIFIED DUMMY TEST

Intermediate Severity Impact

Type II Instrumentation

Frontal Impact

Three Point Belt Restraint

IMPACT PARAMETERS

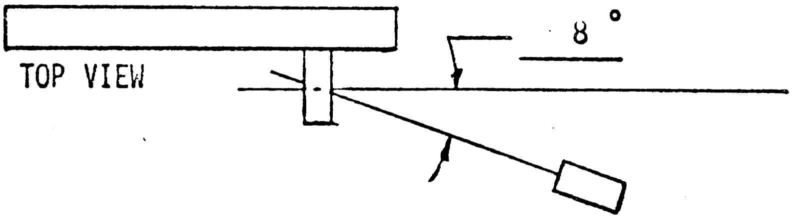
TEST NO.	IMPACT VELOCITY (MPH)	IMPACT DECELERATION (G's)
A-911	22.8	10.2
A-912	22.5	10.4

WBR# Certified Dummy

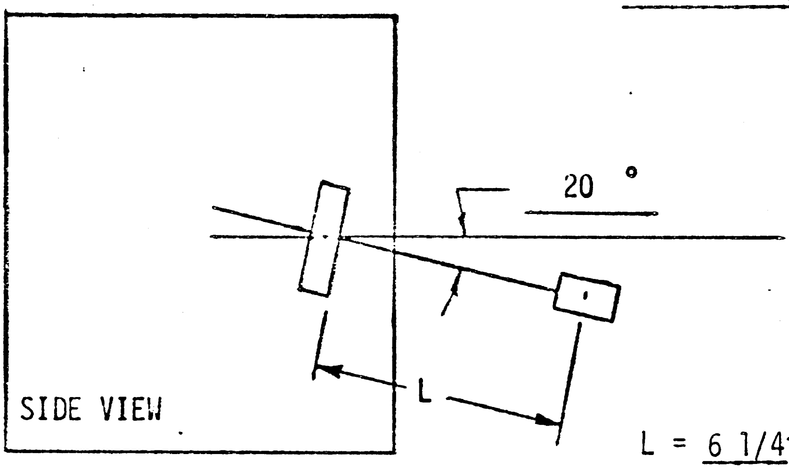
Test No. A-911

WHOLE BODY RESPONSE

BELT ANCHOR ORIENTATIONS

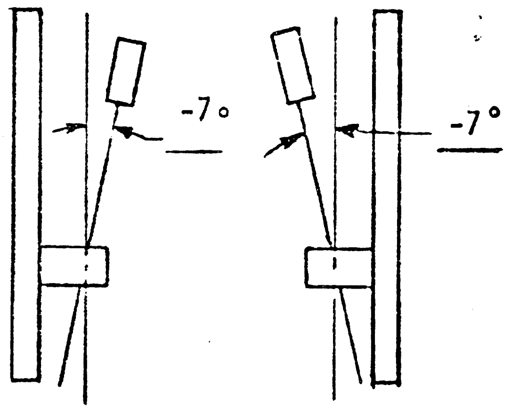


SHOULDER BELT



L = 6 1/4in.

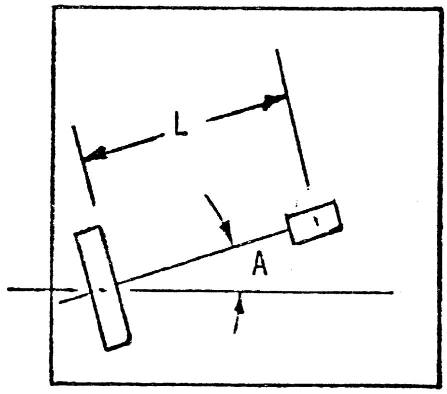
LAP BELT



LEFT SIDE

RIGHT SIDE

TOP VIEW



SIDE VIEW

L_{LEFT} = 5 7/8 in.

L_{RIGHT} = 6 1/8 in.

A_{LEFT} = 51 °

A_{RIGHT} = 52 °

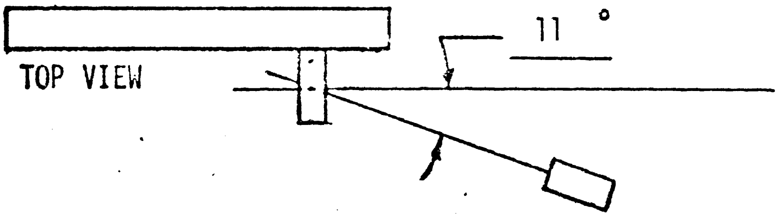
(Sketch indicates Positive Angle directions)

WBR# Certified Dumm

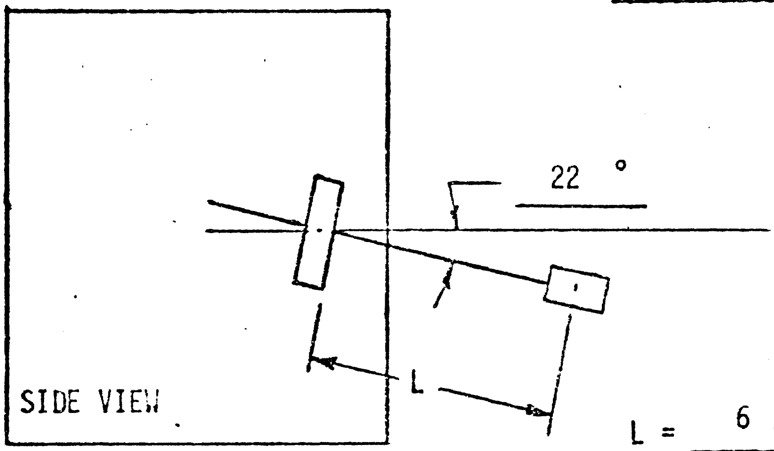
Test No. A-912

WHOLE BODY RESPONSE

BELT ANCHOR ORIENTATIONS

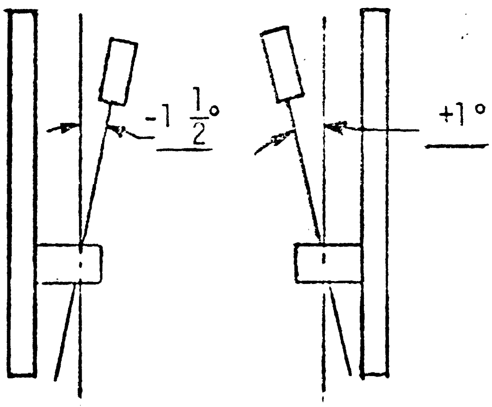


SHOULDER BELT



L = 6 in.

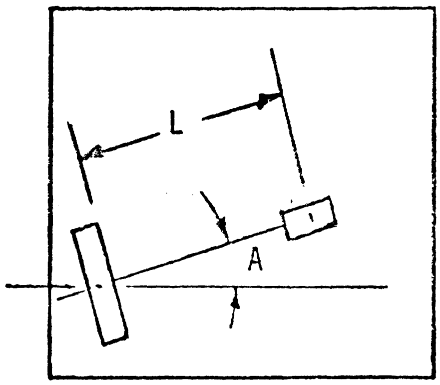
LAP BELT



LEFT SIDE

RIGHT SIDE

TOP VIEW



SIDE VIEW

L_{LEFT} = 5 1/4 in.

L_{RIGHT} = 5 15/16 in.

A_{LEFT} = 52 °

A_{RIGHT} = 53 1/2 °

(Sketch indicates Positive Angle directions)

WHOLE BODY RESPONSE

WBR# Certified Dummy

BELT LENGTH DATA

TEST A- 911

Belt Position	Pre-Impact Length (in)	Post-Impact Length (in)	Belt Stretch (in)	Post-Impact Length with Load Cells
Rt. Lap	12	12	0	11 1/4
Lt. Lap	32 1/2	32 3/4	1/4	32
Shoulder	42	42	0	40 1/2

Test A- 912

Belt Position	Pre-Impact Length (in)	Post-Impact Length (in)	Belt Stretch (in)	Post-Impact Length with Load Cells
Rt. Lap	12	12	12	11 3/8
Lt. Lap	32 1/2	33 1/8	5/8	32 3/8
Shoulder	42	41 3/4	- 1/4	40 3/8

TAPE: GMR-F1

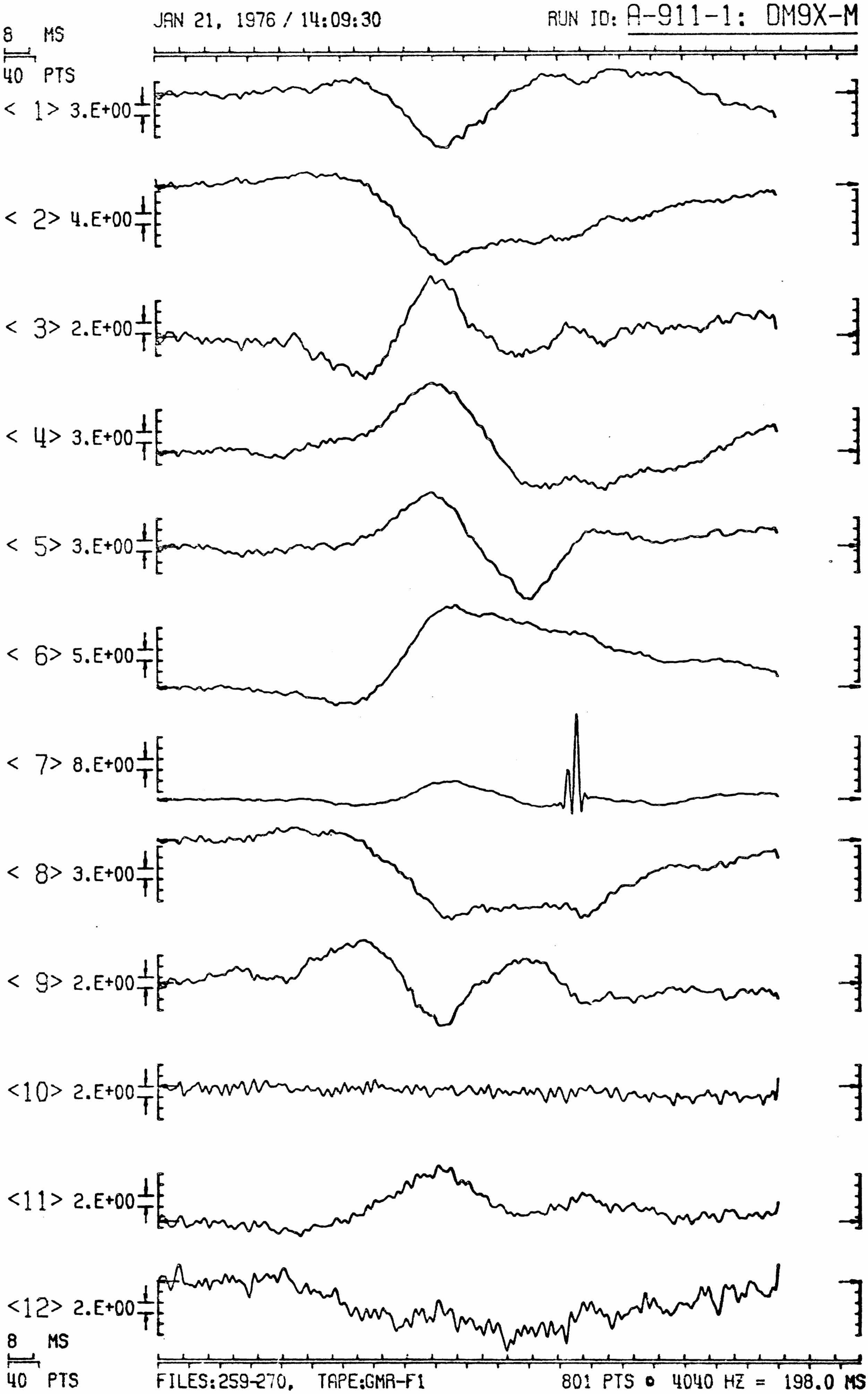
DIGITAL SIGNAL FILTERING
JAN 21, 1976 02:33:16

RUN ID: A-911-1: DM9X-M

PROJECT: WHOLE BODY RESPONSE.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
259 -	1:	ACC-X @ Q1 (HEAD A1)	G'S	801	4041.	LP(090-180)	(3)
260 -	2:	ACC-Y @ Q1 (HEAD B1)	G'S	801	4041.	LP(090-180)	(3)
261 -	3:	ACC-Z @ Q1 (HEAD C1)	G'S	801	4041.	LP(090-180)	(3)
262 -	4:	ACC-X @ Q2 (HEAD C2)	G'S	801	4041.	LP(090-180)	(3)
263 -	5:	ACC-Y @ Q2 (HEAD A2)	G'S	801	4041.	LP(090-180)	(3)
264 -	6:	ACC-Z @ Q2 (HEAD B2)	G'S	801	4041.	LP(090-180)	(3)
265 -	7:	ACC-X @ Q3 (HEAD B3)	G'S	801	4041.	LP(090-180)	(3)
266 -	8:	ACC-Y @ Q3 (HEAD C3)	G'S	801	4041.	LP(090-180)	(3)
267 -	9:	ACC-Z @ Q3 (HEAD A3)	G'S	801	4041.	LP(090-180)	(3)
268 -	10:	HEAD TRIAX A-P ACC	G'S	801	4041.	LP(090-180)	(3)
269 -	11:	HEAD TRIAX S-I ACC	G'S	801	4041.	LP(090-180)	(3)
270 -	12:	HEAD TRIAX L-R ACC	G'S	801	4041.	LP(090-180)	(3)

FILES: 259 - 270 ON TAPE: GMR-F1 RUN: A-911-1: DM9X-M FILTERED JAN 21, 1976 02:33:54


JAN 21, 1976 / 14:09:30
RUN ID: A-911-1: DM9X-M
8 MS
40 PTS
< 1> 3.E+00
< 2> 4.E+00
< 3> 2.E+00
< 4> 3.E+00
< 5> 3.E+00
< 6> 5.E+00
< 7> 8.E+00
< 8> 3.E+00
< 9> 2.E+00
<10> 2.E+00
<11> 2.E+00
<12> 2.E+00
8 MS
40 PTS
FILES:259-270, TAPE:GMR-F1
801 PTS @ 4040 HZ = 198.0 MS

TAPE: GMR-F1

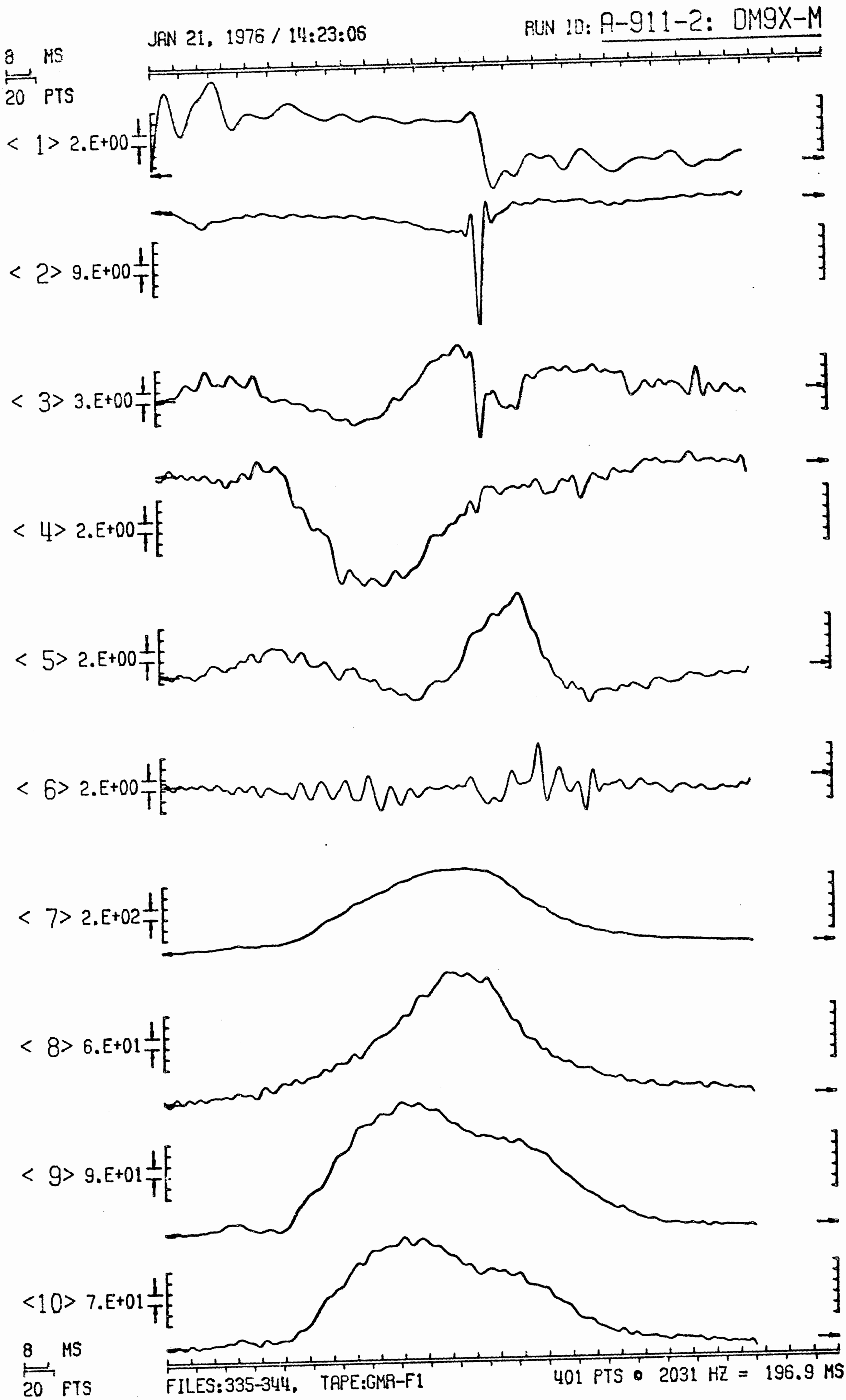
DIGITAL SIGNAL FILTERING
JAN 21, 1976 02:51:37

RUN ID: A-911-2: DM9X-M

PROJECT: WHOLE BODY RESPONSE.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
335 -	1:	SLED DECELERATION	G'S	401	2032.	LP(030-090)	(4)
336 -	2:	PELVIS EXT P-A ACC	G'S	401	2032.	LP(090-225)	(5)
337 -	3:	PELVIS EXT I-S ACC	G'S	401	2032.	LP(090-225)	(5)
338 -	4:	THORAX EXT P-A ACC	G'S	401	2032.	LP(090-225)	(5)
339 -	5:	THORAX EXT I-S ACC	G'S	401	2032.	LP(090-225)	(5)
340 -	6:	THORAX EXT R-L ACC	G'S	401	2032.	LP(090-225)	(5)
341 -	7:	RIGHT LAP BELT LOAD	LBS	401	2032.	LP(090-225)	(5)
342 -	8:	LEFT LAP BELT LOAD	LBS	401	2032.	LP(090-225)	(5)
343 -	9:	UPPER SHOULDER BELT LOAD	LBS	401	2032.	LP(090-225)	(5)
344 -	10:	LOWER SHOULDER BELT LOAD	LBS	401	2032.	LP(090-225)	(5)
	11:						
	12:						

FILES: 335 - 344 ON TAPE: GMR-F1 RUN: A-911-2: DM9X-M FILTERED JAN 21, 1976 02:52:11


JAN 21, 1976 / 14:23:06
RUN ID: A-911-2: DM9X-M
8 MS
20 PTS
< 1> 2.E+00
< 2> 9.E+00
< 3> 3.E+00
< 4> 2.E+00
< 5> 2.E+00
< 6> 2.E+00
< 7> 2.E+02
< 8> 6.E+01
< 9> 9.E+01
<10> 7.E+01
8 MS
20 PTS
FILES:335-344, TAPE:GMR-F1
401 PTS @ 2031 HZ = 196.9 MS

TAPE: GMR-F1

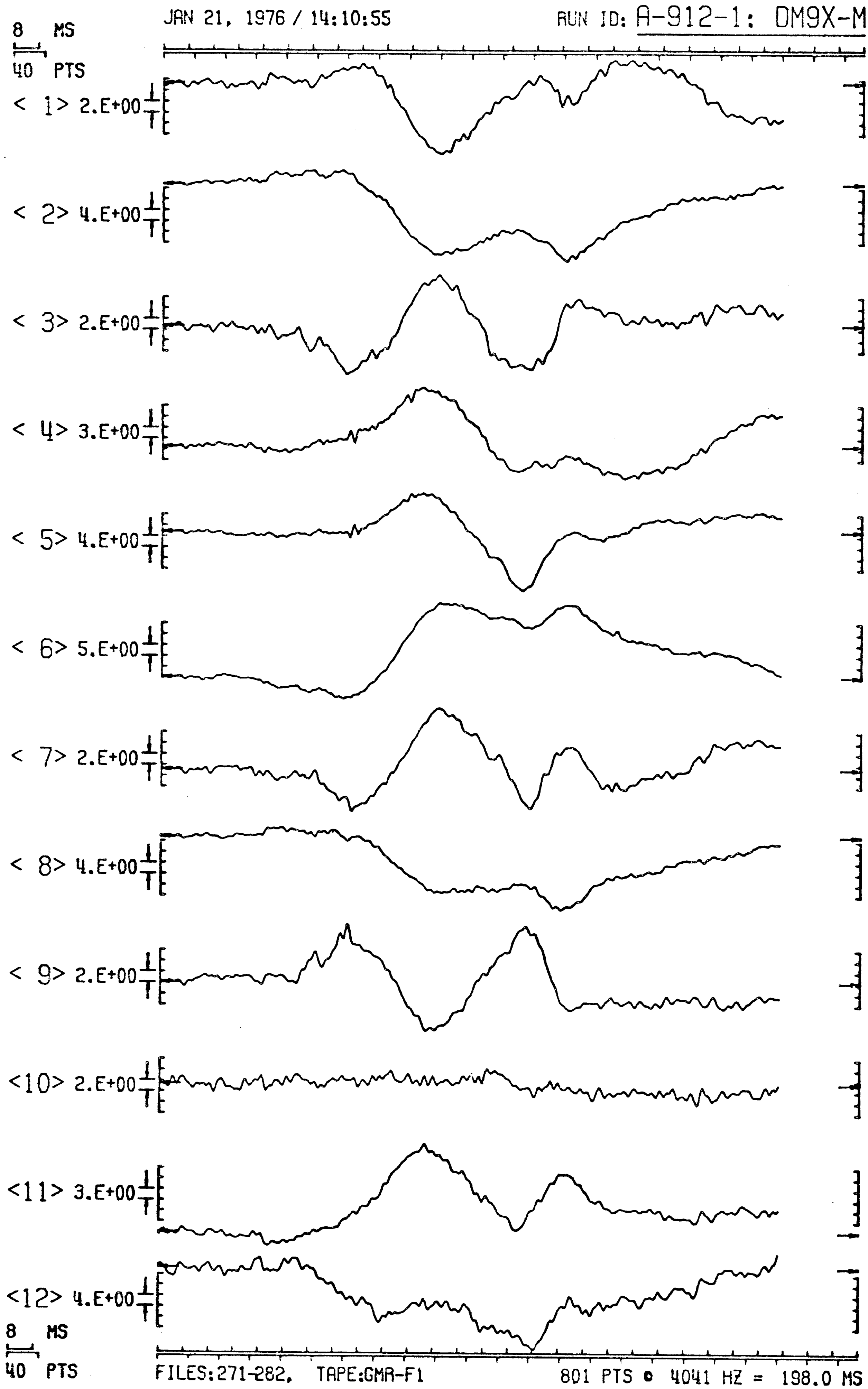
DIGITAL SIGNAL FILTERING
JAN 21, 1976 02:35:11

RUN ID: A-912-1: DM9X-M

PROJECT: WHOLE BODY RESPONSE.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
271 -	1:	ACC-X @ Q1 (HEAD A1)	G'S	801	4041.	LP(090-180)	(3)
272 -	2:	ACC-Y @ Q1 (HEAD B1)	G'S	801	4041.	LP(090-180)	(3)
273 -	3:	ACC-Z @ Q1 (HEAD C1)	G'S	801	4041.	LP(090-180)	(3)
274 -	4:	ACC-X @ Q2 (HEAD C2)	G'S	801	4041.	LP(090-180)	(3)
275 -	5:	ACC-Y @ Q2 (HEAD A2)	G'S	801	4041.	LP(090-180)	(3)
276 -	6:	ACC-Z @ Q2 (HEAD B2)	G'S	801	4041.	LP(090-180)	(3)
277 -	7:	ACC-X @ Q3 (HEAD B3)	G'S	801	4041.	LP(090-180)	(3)
278 -	8:	ACC-Y @ Q3 (HEAD C3)	G'S	801	4041.	LP(090-180)	(3)
279 -	9:	ACC-Z @ Q3 (HEAD A3)	G'S	801	4041.	LP(090-180)	(3)
280 -	10:	HEAD TRIAX A-P ACC	G'S	801	4041.	LP(090-180)	(3)
281 -	11:	HEAD TRIAX S-I ACC	G'S	801	4041.	LP(090-180)	(3)
282 -	12:	HEAD TRIAX L-R ACC	G'S	801	4041.	LP(090-180)	(3)

FILES: 271 - 282 ON TAPE: GMR-F1 RUN: A-912-1: DM9X-M FILTERED JAN 21, 1976 02:35:48


JAN 21, 1976 / 14:10:55
RUN ID: A-912-1: DM9X-M
8 MS
40 PTS
< 1> 2.E+00
< 2> 4.E+00
< 3> 2.E+00
< 4> 3.E+00
< 5> 4.E+00
< 6> 5.E+00
< 7> 2.E+00
< 8> 4.E+00
< 9> 2.E+00
<10> 2.E+00
<11> 3.E+00
<12> 4.E+00
8 MS
40 PTS
FILES:271-282, TAPE:GMR-F1
801 PTS @ 4041 HZ = 198.0 MS

TAPE: GMR-F1

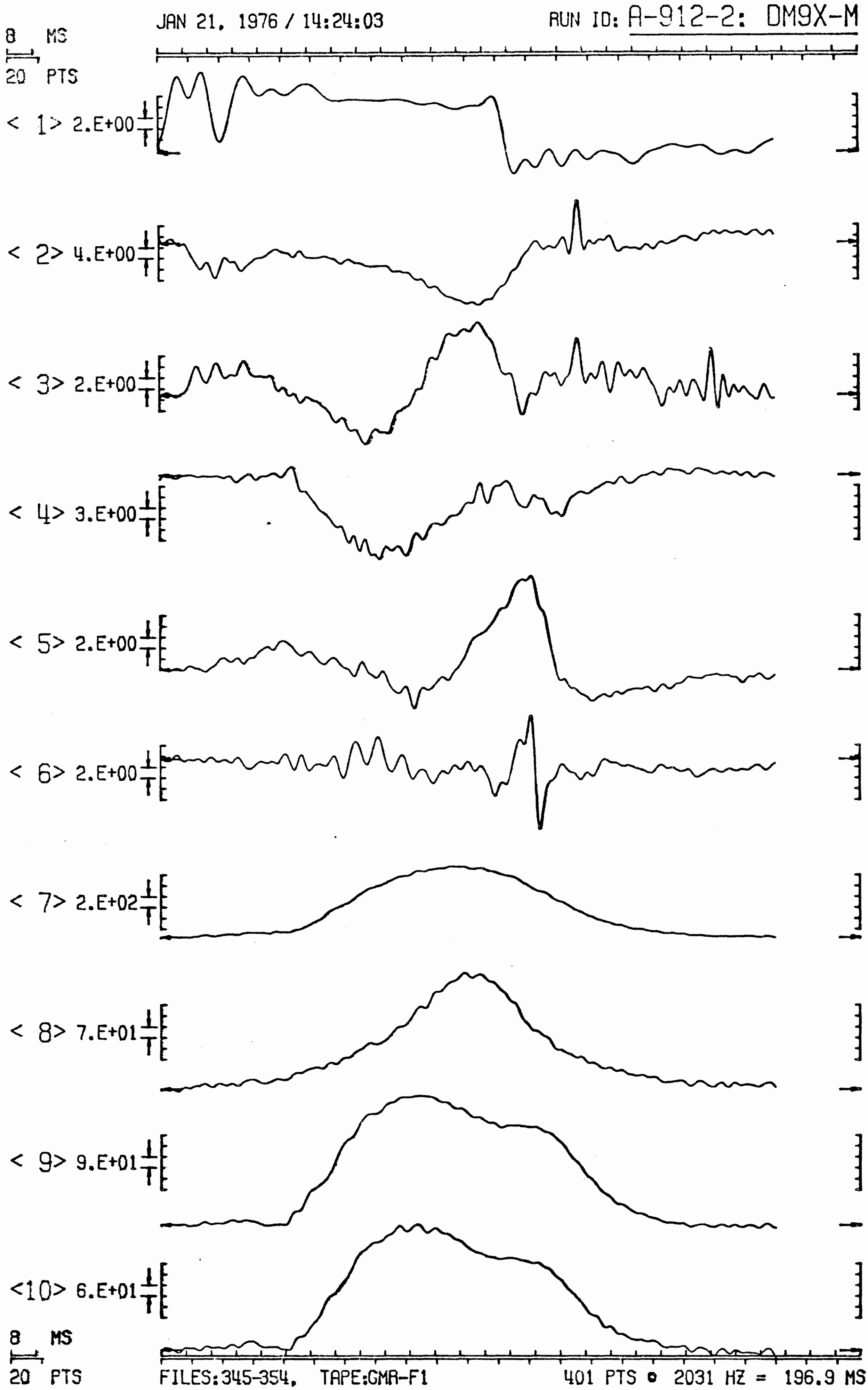
DIGITAL SIGNAL FILTERING
JAN 21, 1976 02:53:23

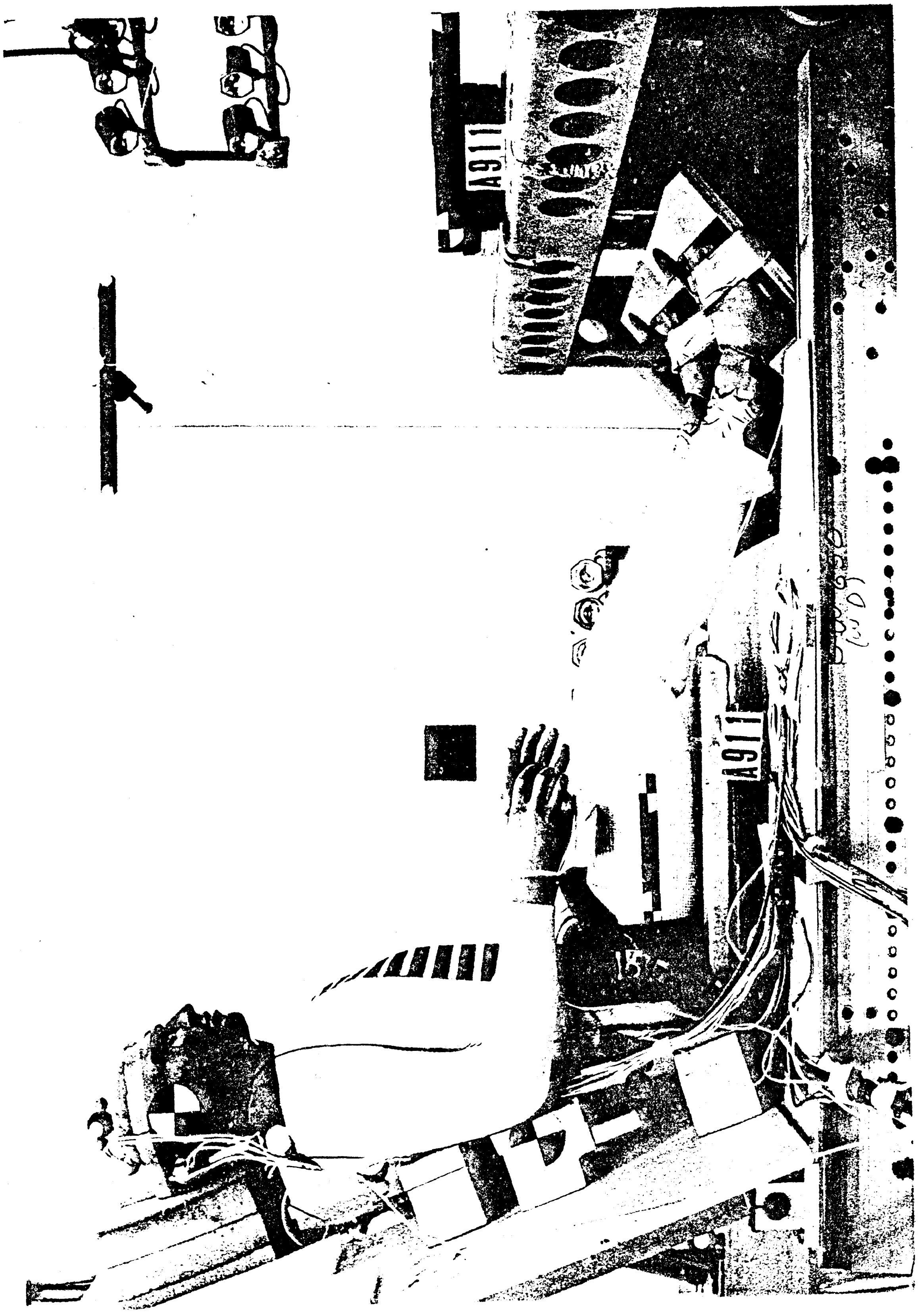
RUN ID: A-912-2: DM9X-M

PROJECT: WHOLE BODY RESPONSE.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
345 -	1:	SLED DECELERATION	G'S	401	2032.	LP(030-090)	(4)
346 -	2:	PELVIS EXT P-A ACC	G'S	401	2032.	LP(090-225)	(5)
347 -	3:	PELVIS EXT I-S ACC	G'S	401	2032.	LP(090-225)	(5)
348 -	4:	THORAX EXT P-A ACC	G'S	401	2032.	LP(090-225)	(5)
349 -	5:	THORAX EXT I-S ACC	G'S	401	2032.	LP(090-225)	(5)
350 -	6:	THORAX EXT R-L ACC	G'S	401	2032.	LP(090-225)	(5)
351 -	7:	RIGHT LAP BELT LOAD	LBS	401	2032.	LP(090-225)	(5)
352 -	8:	LEFT LAP BELT LOAD	LBS	401	2032.	LP(090-225)	(5)
353 -	9:	UPPER SHOULDER BELT LOAD	LBS	401	2032.	LP(090-225)	(5)
354 -	10:	LOWER SHOULDER BELT LOAD	LBS	401	2032.	LP(090-225)	(5)
	11:						
	12:						

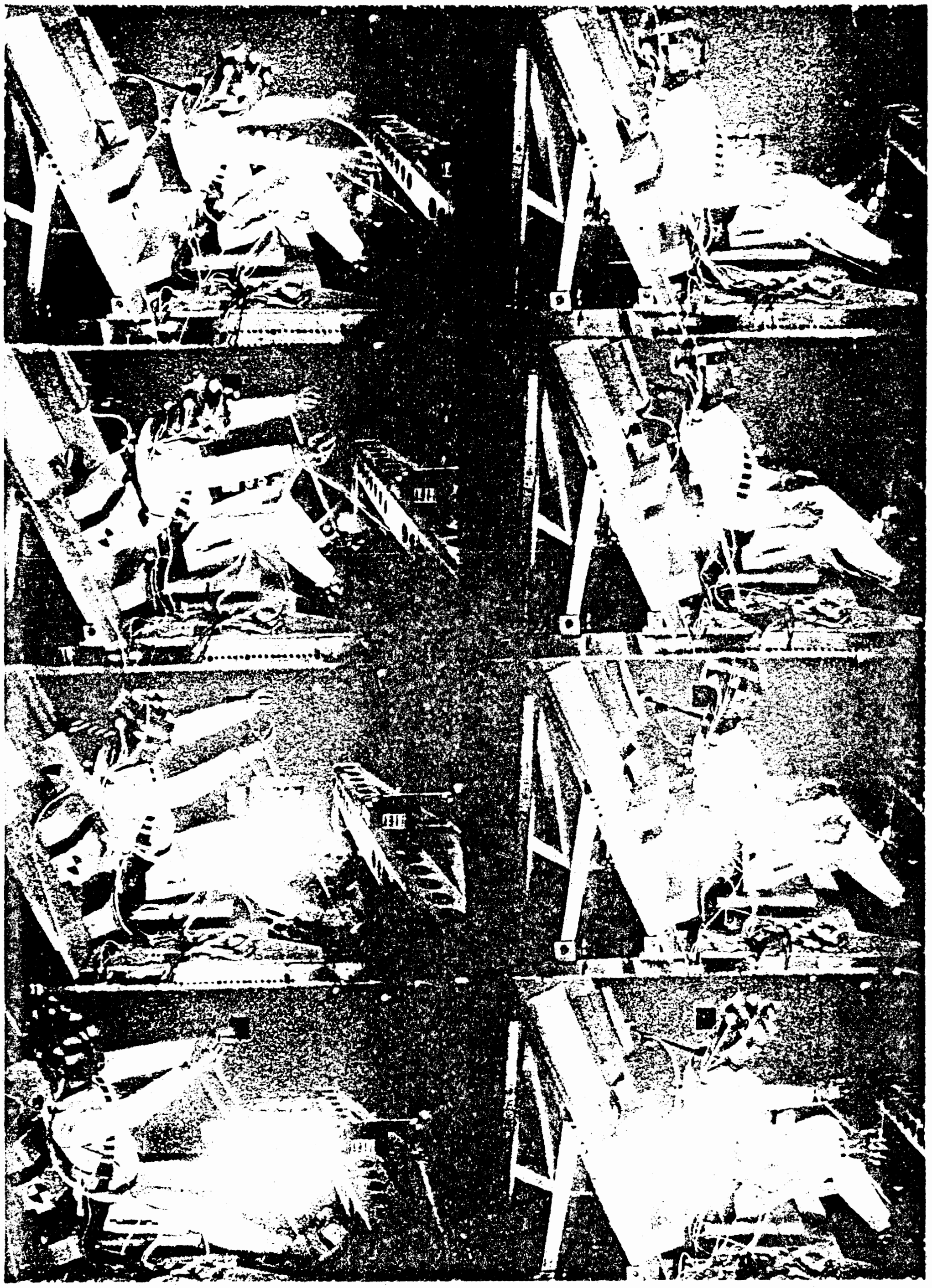
FILES: 345 - 354 ON TAPE: GMR-F1 RUN: A-912-2: DM9X-M FILTERED JAN 21, 1976 02:53:55


JAN 21, 1976 / 14:24:03
RUN ID: A-912-2: DM9X-M
8 MS
20 PTS
< 1> 2.E+00
< 2> 4.E+00
< 3> 2.E+00
< 4> 3.E+00
< 5> 2.E+00
< 6> 2.E+00
< 7> 2.E+02
< 8> 7.E+01
< 9> 9.E+01
<10> 6.E+01
8 MS
20 PTS
FILES:345-354, TAPE:GMA-F1
401 PTS @ 2031 HZ = 196.9 MS

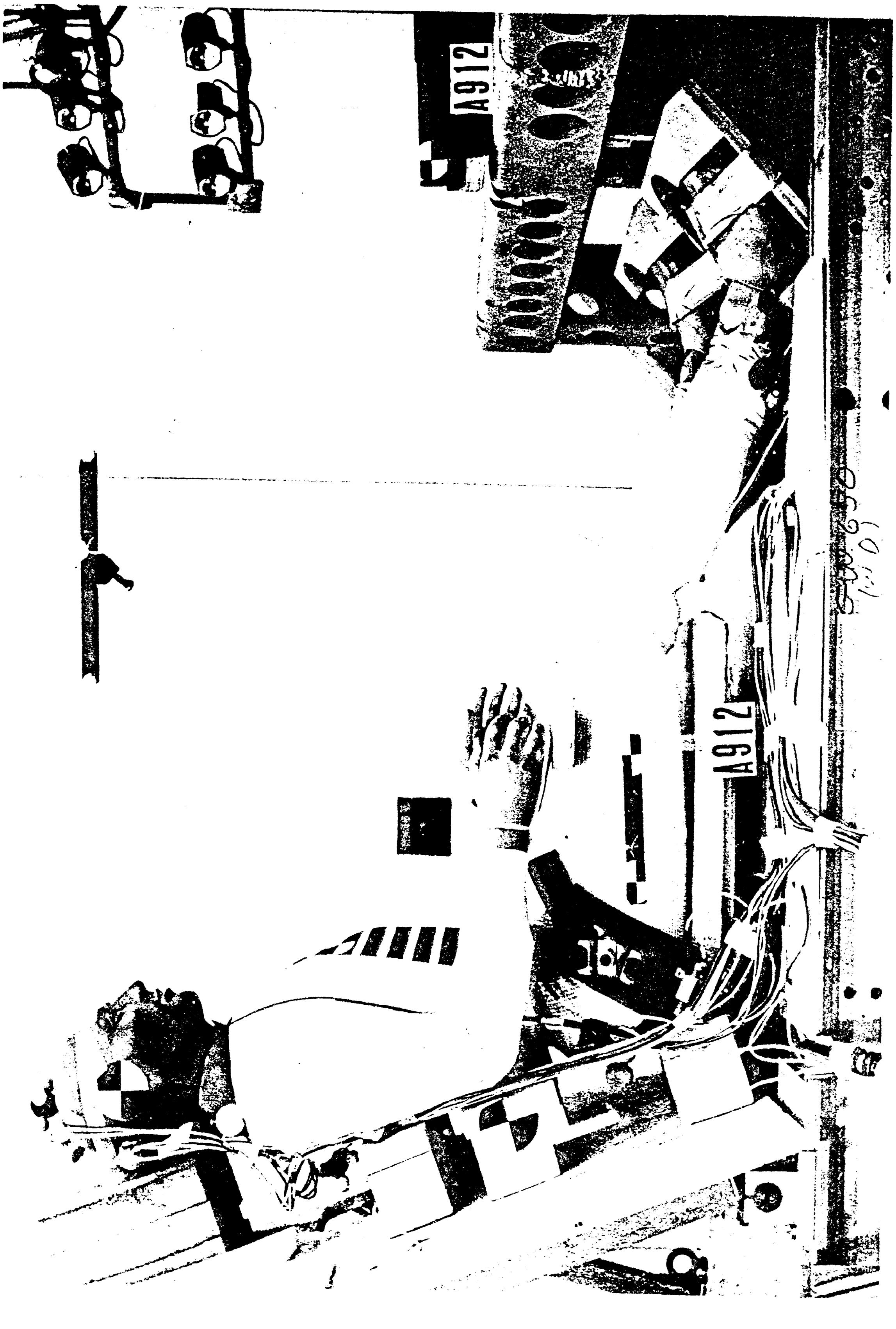


SETUP PHOTOGRAPH: TEST A-911

SETUP PHOTOGRAPH: TEST A-911

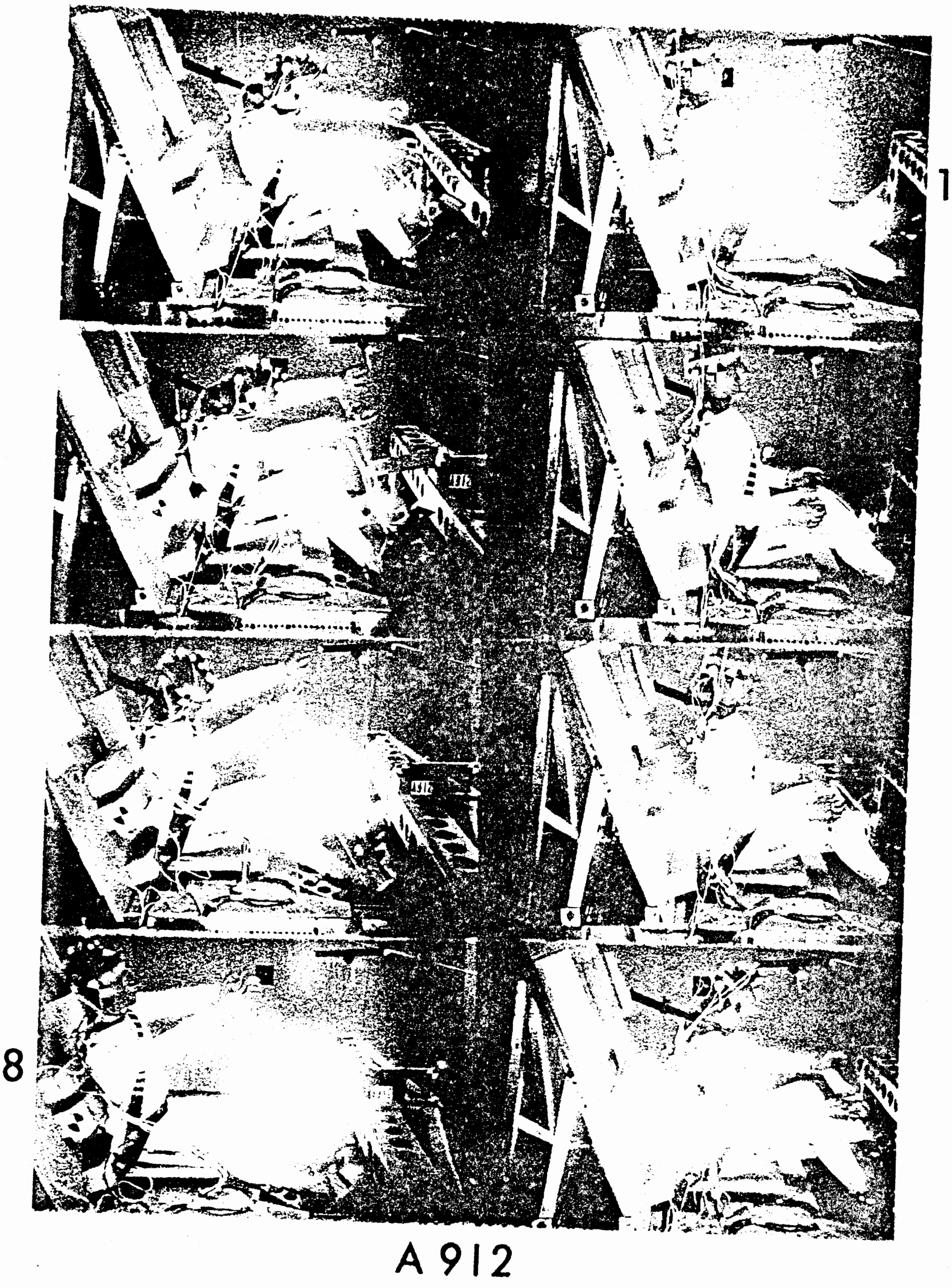


GRAPHCHECK PHOTOGRAPH: TEST A-911



SETUP PHOTOGRAPH: TEST A-912

SETUP PHOTOGRAPH: TEST A-912



GRAPHCHECK PHOTOGRAPH: TEST A-912

WHOLE BODY RESPONSE

CERTIFIED DUMMY TEST

High Severity Impact

Type II Instrumentation

Frontal Impact

Three Point Belt Restraint

IMPACT PARAMETERS

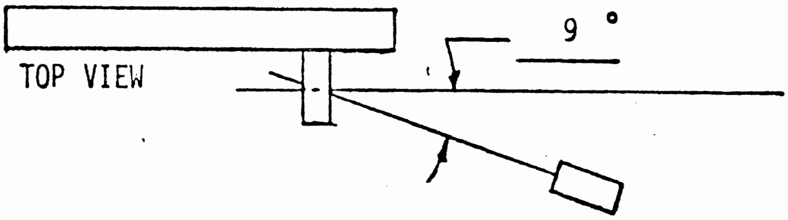
TEST NO.	IMPACT VELOCITY (MPH)	IMPACT DECELERATION (G's)
A-913	32.8	20.0

WBR# Certified Dummy

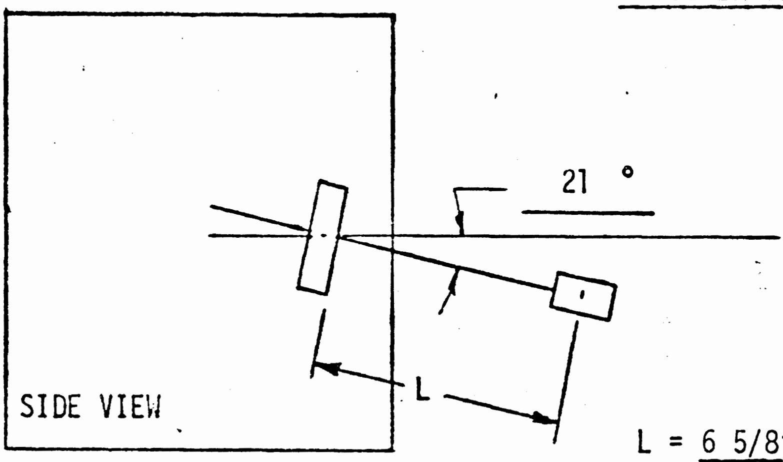
Test No. A-913

WHOLE BODY RESPONSE

BELT ANCHOR ORIENTATIONS

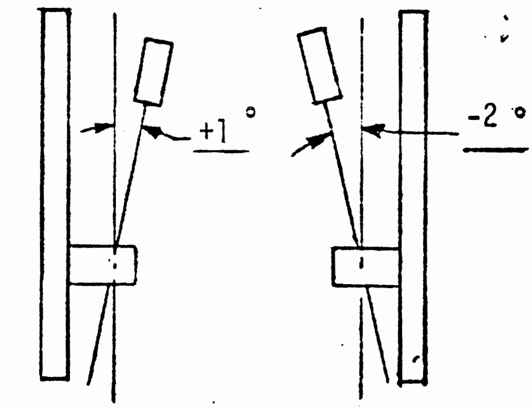


SHOULDER BELT



L = 6 5/8in.

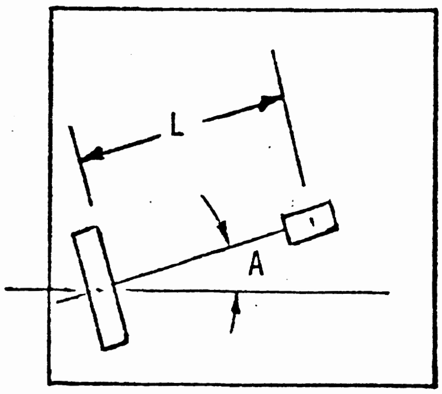
LAP BELT



LEFT SIDE

RIGHT SIDE

TOP VIEW



SIDE VIEW

L_{LEFT} = 5 1/8 in.

L_{RIGHT} = 5 3/4 in.

A_{LEFT} = 52 °

A_{RIGHT} = 53 °

(Sketch indicates Positive Angle directions)

WHOLE BODY RESPONSE WBR# Certified Dummy

BELT LENGTH DATA

TEST A- 913

Belt Position	Pre-Impact Length (in)	Post-Impact Length (in)	Belt Stretch (in)	Post-Impact Length with Load Cells
Rt. Lap	12	12	0	11 3/8
Lt. Lap	32 1/2	32 5/8	1/8	32
Shoulder	42	41 3/4	-1/4	40 1/4

Test A-

Belt Position	Pre-Impact Length (in)	Post-Impact Length (in)	Belt Stretch (in)	Post-Impact Length with Load Cells
Rt. Lap				
Lt. Lap				
Shoulder				

DIGITAL SIGNAL FILTERING
JAN 21, 1976 02:38:21

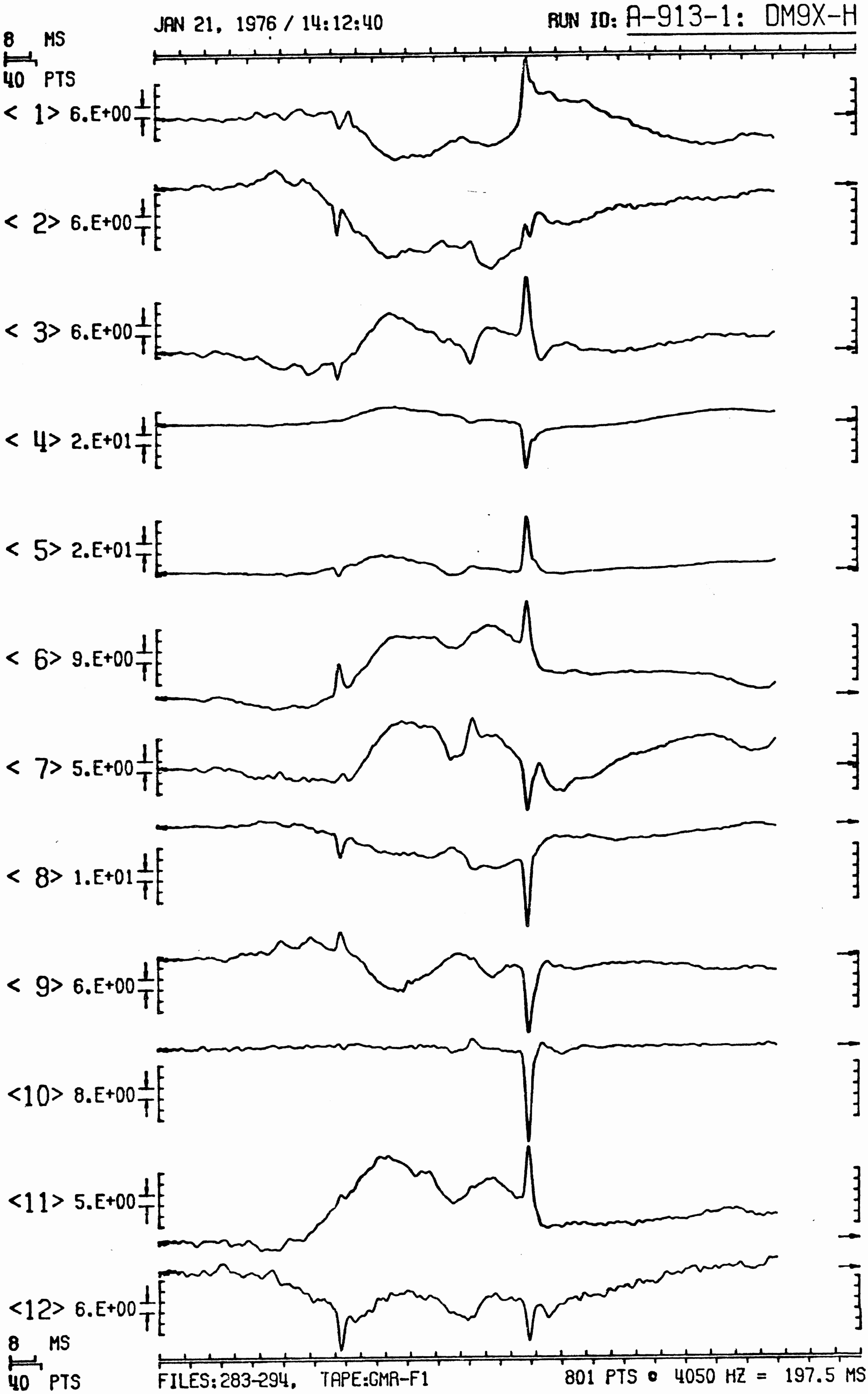
TAPE: GMR-F1

RUN ID: A-913-1: DM9X-M

PROJECT: WHOLE BODY RESPONSE.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
283 -	1:	ACC-X @ Q1 (HEAD A1)	G'S	801	4041.	LP(090-180)	(3)
284 -	2:	ACC-Y @ Q1 (HEAD B1)	G'S	801	4041.	LP(090-180)	(3)
285 -	3:	ACC-Z @ Q1 (HEAD C1)	G'S	801	4041.	LP(090-180)	(3)
286 -	4:	ACC-X @ Q2 (HEAD C2)	G'S	801	4041.	LP(090-180)	(3)
287 -	5:	ACC-Y @ Q2 (HEAD A2)	G'S	801	4041.	LP(090-180)	(3)
288 -	6:	ACC-Z @ Q2 (HEAD B2)	G'S	801	4041.	LP(090-180)	(3)
289 -	7:	ACC-X @ Q3 (HEAD B3)	G'S	801	4041.	LP(090-180)	(3)
290 -	8:	ACC-Y @ Q3 (HEAD C3)	G'S	801	4041.	LP(090-180)	(3)
291 -	9:	ACC-Z @ Q3 (HEAD A3)	G'S	801	4041.	LP(090-180)	(3)
292 -	10:	HEAD TRIAX A-P ACC	G'S	801	4041.	LP(090-180)	(3)
293 -	11:	HEAD TRIAX S-I ACC	G'S	801	4041.	LP(090-180)	(3)
294 -	12:	HEAD TRIAX L-R ACC	G'S	801	4041.	LP(090-180)	(3)

FILES: 283 - 294 ON TAPE: GMR-F1 RUN: A-913-1: DM9X-M FILTERED JAN 21, 1976 02:38:53



JAN 21, 1976 / 14:12:40
RUN ID: A-913-1: DM9X-H
8 MS
40 PTS
< 1> 6.E+00
< 2> 6.E+00
< 3> 6.E+00
< 4> 2.E+01
< 5> 2.E+01
< 6> 9.E+00
< 7> 5.E+00
< 8> 1.E+01
< 9> 6.E+00
<10> 8.E+00
<11> 5.E+00
<12> 6.E+00
8 MS
40 PTS
FILES:283-294, TAPE:GMA-F1
801 PTS @ 4050 HZ = 197.5 MS

TAPE: GMR-F1

DIGITAL SIGNAL FILTERING
JAN 21, 1976 02:54:54

RUN ID: A-913-2: DM9X-H

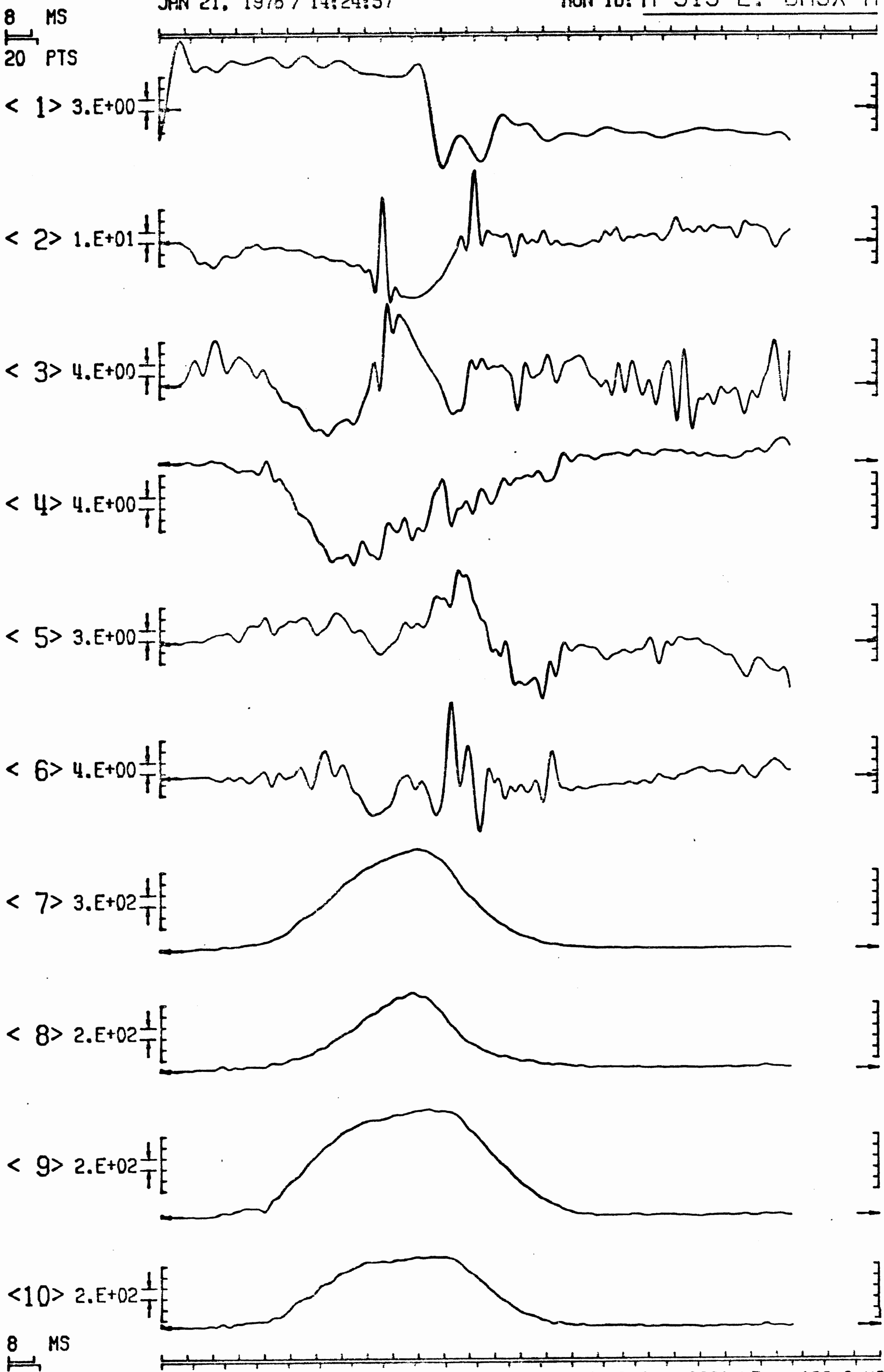
PROJECT: WHOLE BODY RESPONSE.

FILE	CH#	CHANNEL DESCRIPTION	UNITS	PTS	@ HZ	FILTER NAME	NO.
355 -	1:	SLED DECELERATION	G'S	401	2031.	LP(030-090)	(4)
356 -	2:	PELVIS EXT P-A ACC	G'S	401	2031.	LP(090-225)	(5)
357 -	3:	PELVIS EXT I-S ACC	G'S	401	2031.	LP(090-225)	(5)
358 -	4:	THORAX EXT P-A ACC	G'S	401	2031.	LP(090-225)	(5)
359 -	5:	THORAX EXT I-S ACC	G'S	401	2031.	LP(090-225)	(5)
360 -	6:	THORAX EXT R-L ACC	G'S	401	2031.	LP(090-225)	(5)
361 -	7:	RIGHT LAP BELT LOAD	LBS	401	2031.	LP(090-225)	(5)
362 -	8:	LEFT LAP BELT LOAD	LBS	401	2031.	LP(090-225)	(5)
363 -	9:	UPPER SHOULDER BELT LOAD	LBS	401	2031.	LP(090-225)	(5)
364 -	10:	LOWER SHOULDER BELT LOAD	LBS	401	2031.	LP(090-225)	(5)
	11:						
	12:						

FILES: 355 - 364 ON TAPE: GMR-F1 RUN: A-913-2: DM9X-H FILTERED JAN 21, 1976 02:55:26

JAN 21, 1976 / 14:24:57

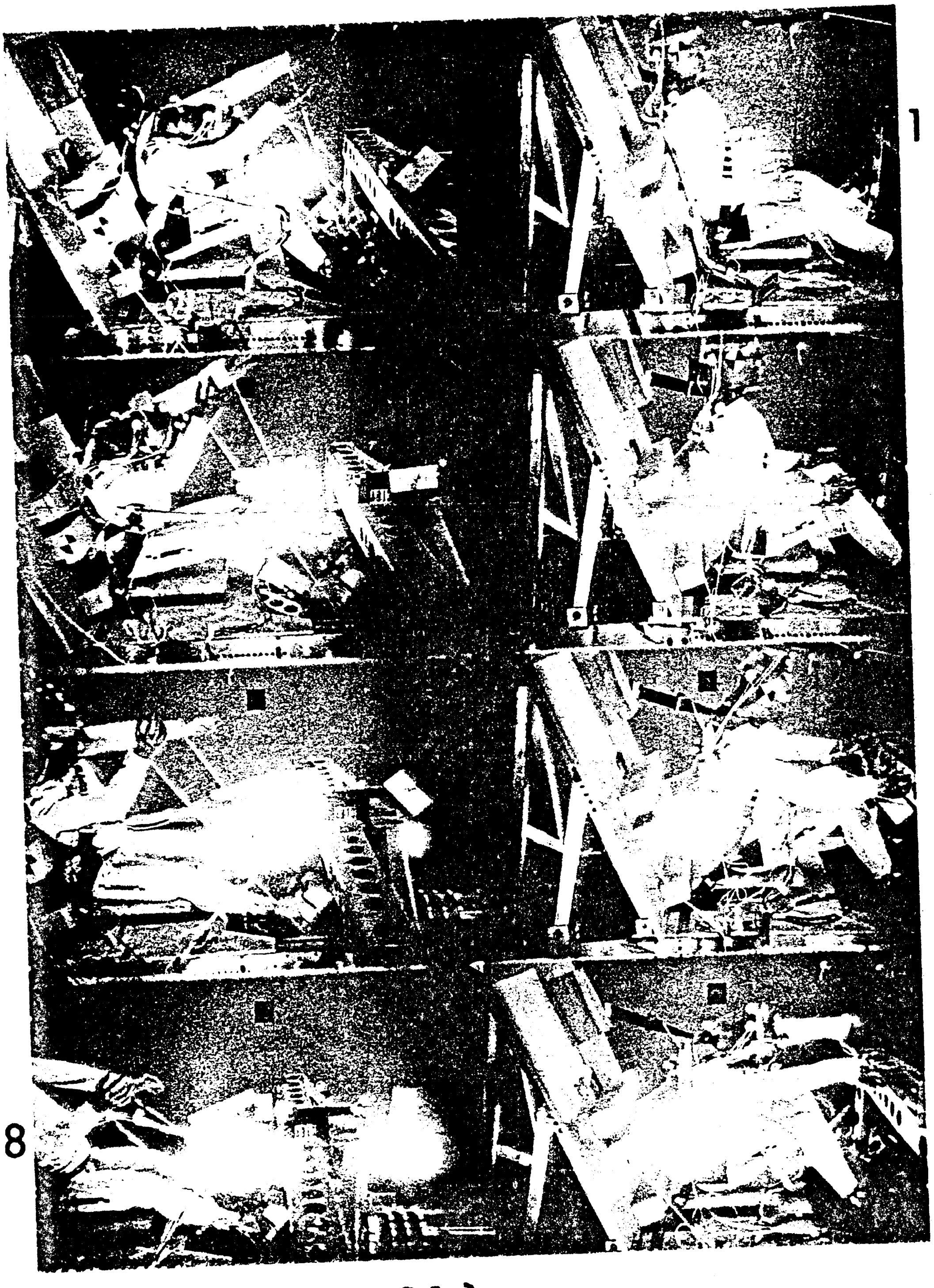
RUN ID: A-913-2: DM9X-H



FILES:355-364, TAPE:GMA-F1

401 PTS @ 2031 HZ = 196.9 MS

SETUP PHOTOGRAPH: TEST A-913



A 913

GRAPHCHECK PHOTOGRAPH: TEST A-913

APPENDIX C

THREE-DIMENSIONAL X-RAY TECHNIQUE

APPENDIX C: THREE DIMENSIONAL X-RAY TECHNIQUE

In mounting accelerometers on the head, it is very difficult to locate them on standard anatomical landmarks and orient them along standard anatomical axes. It is more convenient to mount them in an arbitrary instrumentation frame, then determine the transformation between this frame and a pre-defined, standard anatomical frame.

It is the purpose of this appendix to present a technique using x-rays to determine this transformation.

C.1 Reference System

Let $(\hat{e}_1,\hat{e}_2,\hat{e}_3)$ be an arbitrary instrumentation frame, embedded in the head $(\hat{i},\hat{j},\hat{k})$ a standard anatomical reference frame, and $(\hat{I},\hat{J},\hat{K})$ be an inertial frame. For any given arbitrary orientation of the head in the inertial frame,

$$\left\{\hat{e}_1,\hat{e}_2,\hat{e}_3\right\} = [E]\left\{\hat{I},\hat{J},\hat{K}\right\} \tag{1}$$

and

$$\left\{\hat{i},\hat{j},\hat{k}\right\} = [A]\left\{\hat{I},\hat{J},\hat{K}\right\} \tag{2}$$

The objective is to obtain a transformation matrix of $(\hat{e}_1,\hat{e}_2,\hat{e}_3)$ in the $(\hat{i},\hat{j},\hat{k})$:

$$\left\{\hat{e}_1,\hat{e}_2,\hat{e}_3\right\} = [R]\left\{\hat{i},\hat{j},\hat{k}\right\} \tag{3}$$

It is obvious from (1), (2), (3) that

$$[R] = [E]\,[A]^{-1} \tag{4}$$

Thus to obtain [R], one must obtain [E] and [A], then perform the product of equation (4).

C.2 Landmark Locations

The standard anatomical frame for the head is based on the Frankfort Plane which is defined by four anatomical landmarks: the two superior edges of the right (P_1) and left (P_2) auditory meati, and two right (P_3) and left (P_4) orbital notches. The anatomical center is defined as mid-way between P_1 and P_2, then, and a point M is defined as mid-way point between P_3 and P_4; then

$$\text{anatomical A-P axis} = \hat{i} = \vec{CM}/|CM| \quad (5)$$

$$\text{anatomical L-R axis} = \hat{j} = \vec{CP_2}/|CP_2| \quad (6)$$

$$\text{anatomical S-I axis} = \hat{k} = \hat{i} \times \hat{j} \quad (7)$$

The instrumentation frame is defined by the origin P of $(\hat{e}_1,\hat{e}_2,\hat{e}_3)$ and the 3 accelerometers' center of mass Q_1, Q_2, Q_3:

$$\hat{e}_1 = \vec{PQ_1}/|PQ_1| \quad (8)$$

$$\hat{e}_2 = \vec{PQ_2}/|PQ_2| \quad (9)$$

$$\hat{e}_3 = \vec{PQ_3}/|PQ_3| \quad (10)$$

Therefore it is necessary to devise a method to locate the (x,y,z) coordinates of the 4 anatomical points (P_1,P_2,P_3,P_4) and the 3 instrumentation points (Q_1,Q_2,Q_3) before matrices [E] and [A] are known, and subsequently, matrix [R].

This method was described in the First Year Final Report [UM-HSRI-BI 75-1] and has been very satisfactory. However, the computational procedure of the origin P has been modified which results in the proper solution. In addition, a perturbation scheme has been introduced to bring the resulting matrix [R] to a perfect orthogonality.

C.3 Location of Instrumentation Origin P

Given

x_1, y_1, z_1 of Q_1 and $PQ_1 = \rho_1$

x_2, y_2, z_2 of Q_2 and $PQ_2 = \rho_2$

x_3, y_3, z_3 of Q_3 and $PQ_3 = \rho_3$

and assuming that Q_1, Q_2, Q_3 are located on the respective axes of an instrumentation right-handed triad, it is required to find x_p, y_p, z_p of the origin P of $(\hat{e}_1, \hat{e}_2, \hat{e}_3)$.

The origin P is the intersection of 3 spheres of centers Q_1, Q_2, Q_3 and radii ρ_1, ρ_2, ρ_3. It is possible to write the equations of these spheres in 3-D, but these equations are quadratic equations in (x_p, y_p, z_p) which means that two solutions may be obtained. Furthermore, both solutions yield a right handed triad when associated with Q_1, Q_2, Q_3. Thus, alternate method is devised which will yield a unique solution which is proved to be the proper one. This method, presented below, uses intersection of lines and planes, to find the correct location of P.

Consider spheres (Q_1, ρ_1) and (Q_2, ρ_2). In order for P to exist, they must intersect along a circle with center at H_1 which must be located on line Q_1Q_2 connecting the centers. Furthermore, this circle is the locus of origin P, thus it has a radius H_1P. The third sphere (Q_3, ρ_3) being orthogonal to each of the first two, must intersect the circle (H_1, H_1P) at right angles, i.e., Q_3P must be tangent to that circle. Therefore, the plane Q_3PH_1 is normal to line Q_1Q_2, or line Q_1Q_2 must be normal to all lines contained in plane Q_3PH_1; in particular Q_1Q_2 is perpendicular to line

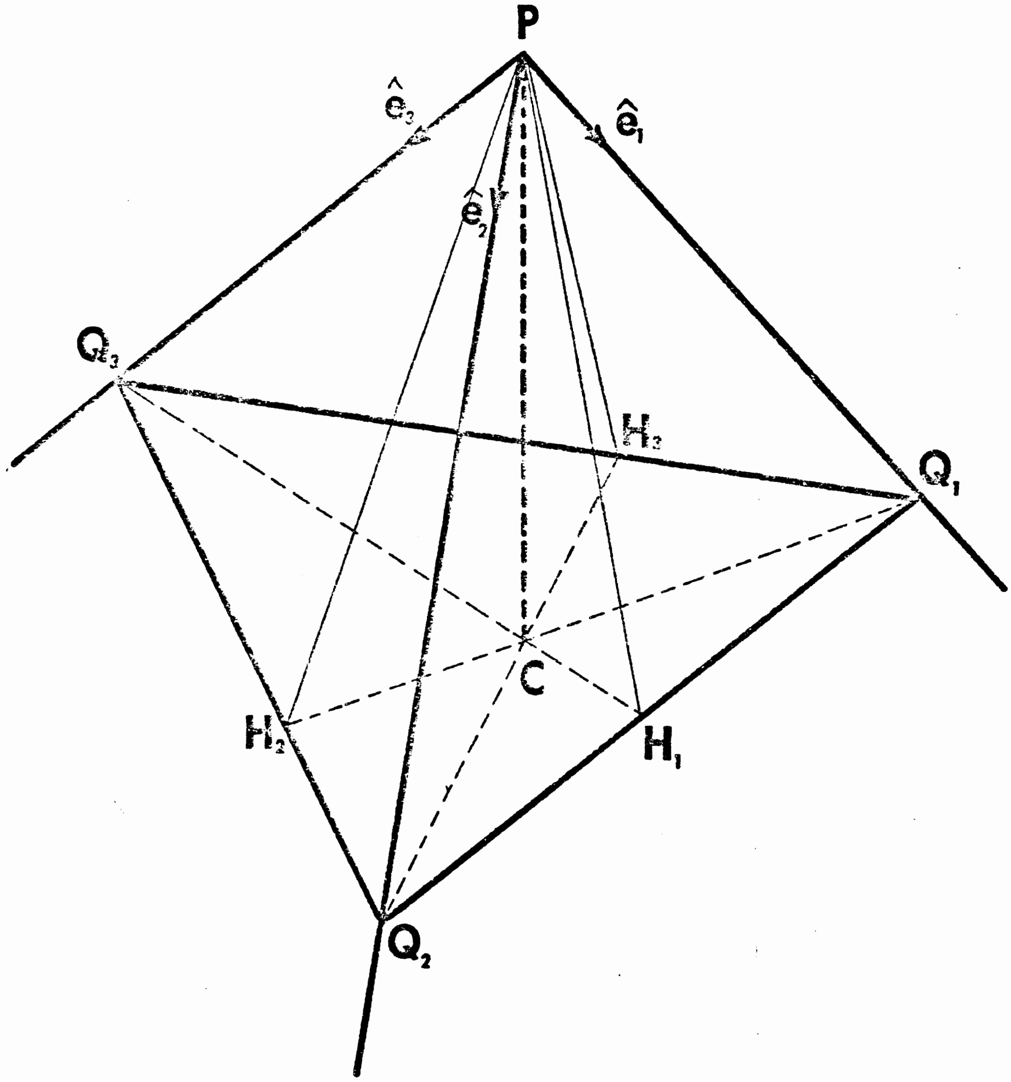


Figure C-1

Q_3H_1. Thus, Q_3H_1 is the height of triangle $Q_1Q_2Q_3$ at the base Q_1Q_2. Similar reasoning may be followed for each of the other two heights Q_2H_3 and Q_1H_2. Since all three heights in any triangle intersect at a common point, this intersection is called point C.

Next, consider plane Q_3H_1P which is perpendicular to Q_1Q_2. Since point C is in this plane, line CP must be perpendicular to Q_1Q_2. Similarly, CP must be perpendicular to Q_2Q_3 and to Q_3Q_1. It may be concluded that line CP is perpendicular to the plane of the triangle $Q_1Q_2Q_3$, or that C is the orthogonal projection of a single point P on the plane $Q_1Q_2Q_3$.

Armed with these properties, the solution of the problem may be broken into smaller problems of line-plane intersections.

Given a plane defined by a point (x_1,y_1,z_1) and the direction cosines of a normal vector (a, b, c), and given a line defined by a point (x_2,y_2,z_2) and its direction cosines (u, v, w), solve for the trace (x, y, z) of the line on the plane.

The normal form of the equation of the plane is:

$$a(x - x_1) + b(y - y_1) + c(z - z_1) = 0 \tag{11}$$

and the parametric form of the equation of the line:

$$\begin{aligned} x &= x_2 + ut \\ y &= y_2 + vt \\ z &= z_2 + zt \end{aligned} \tag{12}$$

At the intersection, (x, y, z) must satisfy both equation (11) and (12):

$$a[(x_2 + ut) - x_1] + b[(y_2 + vt) - y_1] + c[(z_2 + wt) - z_1] = 0 \tag{13}$$

which yields:

$$t = \frac{a(x_1 - x_2) + b(y_1 - y_2) + c(z_1 - z_2)}{a\,u + b\,v + c\,w} \tag{14}$$

The parameter t is precisely the distance along (u, v, w) of the line between the piercing point and the line's particular point. Once it is computed from equation (14), it is substituted in equation (12) to yield the coordinate (x, y, z) of the intersection.

The first step towards a solution is to compute the location of H_1 as the intersection of Q_1Q_2 whose direction cosines and particular points are known, and the plane Q_3H_1P which has the same direction cosines as Q_1Q_2 and a particular point Q_3. This is repeated for H_2 and H_3.

The second step is to locate C as the intersection of line Q_3H_1 and plane Q_1H_2P whose direction cosines and particular points are known. The location of C may be obtained with two other methods: intersection of line Q_1H_2 with plane Q_2H_3P, or intersection of line Q_2H_3 with plane Q_3H_1P. One method is sufficient, but the average of the 3 methods reduces the experimental reading errors.

The direction cosines of line CP are obtained as the normal vector to any two vectors connecting 3 points (Q_1,Q_2,Q_3). The proper order is important so that point P would be on the correct side of the plane (Q_1,Q_2,Q_3). The direction cosines (u_1,u_2,u_3) of this vector $\hat{u}$ are:

$$\hat{u} = \overrightarrow{Q_2Q_1} \times \overrightarrow{Q_1Q_3} \,/\, \left| \overrightarrow{Q_2Q_1} \times \overrightarrow{Q_1Q_3} \right| \tag{15}$$

To complete the required information, the magnitude of line CP must be computed. Again there are three methods which would yield that length. The average is taken to minimize experimental error. The length CP is obtained by solving the right-angle triangle Q_3CP, given Q_3, C and ρ_3. The procedure is repeated using (Q_1, C, ρ_1 - triangle Q_1CP) and (Q_2, C, ρ_2 - triangle Q_2CP), and the average CP is retained.

Finally, the parametric equations of line CP are used to compute the location of P:

$$\begin{aligned} x_p &= x_c + |CP|\ u_1 \\ y_p &= y_c + |CP|\ u_2 \\ z_p &= z_c + |CP|\ u_3 \end{aligned} \tag{15}$$

Once P islocated, the components of $\hat{e}_1$, $\hat{e}_2$, and $\hat{e}_3$ may be determined with equations (8), (9) and (10).

C.4 Perturbation Towards an Orthogonal Matrix

Since the transformation matrix [R] is computed using experimental readings, its elements will carry some error. Fortunately, this matrix must be orthogonal, a property which can be used to determine the amount of error and to perturbate its elements so that it becomes as close to being orthogonal as desired.

Given the uncorrected matrix:

$$\begin{Bmatrix} \hat{e}_1 \\ \hat{e}_2 \\ \hat{e}_3 \end{Bmatrix} = [R] \begin{Bmatrix} \hat{I} \\ \hat{J} \\ \hat{K} \end{Bmatrix} \tag{16}$$

the magnitudes of e_1, e_2 and e_3 must be unity. If the deviation from unity is not acceptable, the following scheme is employed as a new unit vector is computed using normalized versions of the other two:

$$\begin{aligned} e_1^* &= [e_2/|e_2|] \times [e_3/|e_3|] \\ e_2^* &= [e_3/|e_3|] \times [e_1/|e_1|] \\ e_3^* &= [e_1/|e_1|] \times [e_2/|e_2|] \end{aligned} \tag{17}$$

then the old components are replaced by:

$$\begin{aligned} e_1 &= 1/2\ [e_1^* + e_1] \\ e_2 &= 1/2\ [e_2^* + e_2] \\ e_3 &= 1/2\ [e_3^* + e_3] \end{aligned} \tag{18}$$

If the new values of e_1, e_2, e_3 are not acceptable, another iteration is performed. A check on the orthogonality of the matrix is:

$$[R]\ [R]^T = [I] \tag{19}$$

This equation will be true only if:

$$[R]^T = [R]^I \tag{20}$$

i.e., when [R] is orthogonal. It was found that 5 iterations were required for the worst case, a case in which the off-diagonal terms of equation (19) started with as high as 0.18 and ended with 0.00001. Note that none of the 3 unit vectors were perturbed more than four degrees in space, an amount which can conceivably be produced by measurement errors.

APPENDIX D

VALIDATION OF MINIMUM-INPUT

3-D MOTION MEASUREMENT

APPENDIX D: VALIDATION OF MINIMUM-INPUT 3-D MOTION MEASUREMENT

The six-accelerometer method for measuring a general three-dimensional motion is validated using hypothetical and experimental acceleration readings. Results show that the 2-2-2 combination of accelerometers prove to be stable for the durations of the tested motions. Small deviations result from truncation and round-off errors, but considerably larger errors result from the calibration of accelerometers and from the uncertainties in measuring other physical quantities required for the analysis. The effect of both types of errors is cumulative, increasing the instability of integration. The use of additional (redundant) measures is therefore recommended.

This presentation is included in this report for general information purposes. The work was performed for use on a variety of projects at HSRI involved in 3-D motion measurement.

D.1 INTRODUCTION

It has been established that six independent acceleration readings are necessary and sufficient for the determination of a general 3-dimensional motion [1]*. However, it has been the experience of many researchers that, almost always, the six-accelerometer method results in instability of the integration of angular accelerations into angular velocities.

In this paper, the accuracy of the 2-2-2 combination of accelerometers [2] is investigated. The procedure is to carry on the analysis of 6 input accelerations, which are the result of a known motion. This motion is either mathematically prescribed or experimentally produced. In the first (hypothetical) case, all variables of the motions are exactly known, and in the second (experimental) case, only the acceleration in a given direction is measured. In both cases, the computed motion is validated against what is known to be the actual motion.

D.2 INSTRUMENTATION AND KINEMATIC EQUATIONS

A rigid body, shown in Figure 1, moving in inertial frame $(\hat{I},\hat{J},\hat{K})$ is instrumented with 6 accelerometers with their sensitive axes along an instrumentation frame $(\hat{e}_1,\hat{e}_2,\hat{e}_3)$, embedded in the rigid body.

The accelerometers are mounted in pairs at 3 points Q_1, Q_2, Q_3. The origin of the instrumentation frame is P, as shown in figure 1. The absolute accelerations are:

for Q_1

$$\vec{PQ}_1 = \rho_1 \hat{e}_1$$

$$\vec{a}_1 = a_{11}\hat{e}_1 + a_{21}\hat{e}_2 + a_{31}\hat{e}_3, \qquad (1)$$

for Q_2

$$\vec{PQ}_2 = \rho_2 \hat{e}_2$$

$$\vec{a}_2 = a_{12}\hat{e}_1 + a_{22}\hat{e}_2 + a_{32}\hat{e}_3, \qquad (2)$$

*Numbers in brackets refer to references at end of paper.

for Q_3 $$\overrightarrow{PQ}_3 = \rho_3\hat{e}_3$$

$$\vec{a}_3 = a_{13}\hat{e}_1 + a_{23}\hat{e}_2 + a_{33}\hat{e}_3. \tag{3}$$

The angular velocity and acceleration are

$$\dot{\vec{\omega}} = \dot{\omega}_1\hat{e}_1 + \dot{\omega}_2\hat{e}_2 + \dot{\omega}_3\hat{e}_3 \tag{4}$$

$$\vec{\omega} = \omega_1\hat{e}_1 + \omega_2\hat{e}_2 + \omega_3\hat{e}_3 \tag{5}$$

Since a_{11}, a_{22} and a_{33} are not measured for the 2-2-2 configuration of this six-acceleration method, the motion is to be determined using only the other 6 acceleration readings. Kinematic equations are written and manipulated to produce two sets of equations. The first is a set of three simultaneous, nonlinear, first-order differential equations in angular velocity and acceleration:

$$\begin{Bmatrix} \dot{\omega}_1 \\ \dot{\omega}_2 \\ \dot{\omega}_3 \end{Bmatrix} = \begin{bmatrix} \frac{\rho_1}{\rho_2\rho_3} & -\frac{1}{\rho_3} & -\frac{1}{\rho_2} \\ -\frac{1}{\rho_3} & \frac{\rho_2}{\rho_1\rho_3} & -\frac{1}{\rho_1} \\ -\frac{1}{\rho_2} & -\frac{1}{\rho_1} & \frac{\rho_3}{\rho_1\rho_2} \end{bmatrix} \begin{Bmatrix} \frac{a_{12}-a_{13}}{2} \\ \frac{a_{23}-a_{21}}{2} \\ \frac{a_{31}-a_{32}}{2} \end{Bmatrix} + \begin{bmatrix} 0 & \frac{\rho_1}{\rho_2} & -\frac{\rho_1}{\rho_3} \\ -\frac{\rho_2}{\rho_1} & 0 & \frac{\rho_2}{\rho_3} \\ \frac{\rho_3}{\rho_1} & -\frac{\rho_3}{\rho_2} & 0 \end{bmatrix} \begin{Bmatrix} \omega_2\omega_3 \\ \omega_3\omega_1 \\ \omega_1\omega_2 \end{Bmatrix} \quad (6)$$

The second is a set of algebraic equations in the translational acceleration of the origin P:

$$\begin{Bmatrix} A_1 \\ A_2 \\ A_3 \end{Bmatrix} = \begin{Bmatrix} \frac{a_{12}+a_{13}}{2} \\ \frac{a_{23}+a_{21}}{2} \\ \frac{a_{31}+a_{32}}{2} \end{Bmatrix} + \begin{bmatrix} 0 & -\frac{\rho_2}{\rho_1} & \frac{\rho_3}{\rho_1} \\ \frac{\rho_1}{\rho_2} & 0 & -\frac{\rho_3}{\rho_2} \\ -\frac{\rho_1}{\rho_3} & \frac{\rho_2}{\rho_3} & 0 \end{bmatrix} \begin{Bmatrix} \frac{a_{12}-a_{13}}{2} \\ \frac{a_{23}-a_{21}}{2} \\ \frac{a_{31}-a_{32}}{2} \end{Bmatrix} + \begin{bmatrix} \frac{\rho_2\rho_3}{\rho_1} & -\rho_3 & -\rho_2 \\ -\rho_3 & \frac{\rho_3\rho_1}{\rho_2} & -\rho_1 \\ -\rho_2 & -\rho_1 & \frac{\rho_1\rho_2}{\rho_3} \end{bmatrix} \begin{Bmatrix} \omega_2\omega_3 \\ \omega_3\omega_1 \\ \omega_1\omega_2 \end{Bmatrix} \quad (7$$

In general, the instrumentation frame is arbitrarily mounted, and one is interested in expressing the various vectors along an "anatomical" frame which is precisely defined for the rigid body in question. This can easily be done once the transformation between the instrumentation and anatomical frames is known; i.e., one must know the Euler matrix between $(\hat{e}_1,\hat{e}_2,\hat{e}_3)$ and the anatomical frame $(\hat{i},\hat{j},\hat{k})$, and the location of the origin P relative to the anatomical center C, expressed in the anatomical $(\hat{i},\hat{j},\hat{k})$.

A computer program was written to analyze the 3-D motion under these conditions. It requires the knowledge of the following:

1. three distances ρ_1, ρ_2 and ρ_3,
2. six acceleration readings a_{21}, a_{31}, a_{32}, a_{12}, a_{13}, a_{23},
3. the Euler matrix of $(\hat{e}_1,\hat{e}_2,\hat{e}_3)$ relative to $(\hat{i},\hat{j},\hat{k})$,
4. the location of P in the $(\hat{i},\hat{j},\hat{k})$ frame,
5. the location of a body point (e.g. center of mass) in the $(\hat{i},\hat{j},\hat{k})$ frame,
6. four sets of initial conditions: initial angular velocities along $(\hat{e}_1,\hat{e}_2,\hat{e}_3)$, initial Euler angles, initial velocity, initial position of the body point.

The program produces then the following outputs:

1. Angular accelerations and velocity in the $(\hat{i},\hat{j},\hat{k})$,
2. the Euler angular rates and Euler angles relative to the inertial frame $(\hat{I},\hat{J},\hat{K})$,
3. the translational acceleration vector, of the given body-point expressed in the anatomical $(\hat{i},\hat{j},\hat{k})$ and the inertial $(\hat{I},\hat{J},\hat{K})$ frames,
4. the velocity and position vectors of the given body point in the inertial frame.

D.3 HYPOTHETICAL MOTION

The six degrees of freedom of motion are prescribed with the mathematical function:

$$S(t) = S_m[\sin 2\pi f_1 t - \sin 2\pi f_2 t]$$

which has a velocity (1st time-derivative):

$$\dot{S}(t) = 2\pi S_m[f_1 \cos 2\pi f_1 t - f_2 \cos 2\pi f_2 t]$$

and an acceleration (2nd time-derivative)

$$\ddot{S}(t) = -4\pi^2 S_m[f_1^2 \sin 2\pi f_1 t - f_2^2 \sin 2\pi f_2 t]$$

by selecting (S_m, f_1, f_2) for each of the degrees of freedom, and by specifying the location of Q_1, Q_2, Q_3, the accelerations "readings" at these points may be computed, along with the intermediate motion variables which will later be compared to the various output of the 3-D analysis program.

Several tests were conducted successfully, but only test HYP-81 will be presented. The duration of the test was 11.55 milliseconds, and data was sampled at the rate of 25 kHz resulting in 288 reading samples.

The six degrees of freedom for the motion were specified according to the following table:

	S_m	f_1(Hz)	f_2(Hz)
x(t):	0.5 inches	250.	20.
y(t):	0.1 inches	100.	300.
z(t):	1.25 inches	0.	150.
ψ(t):	2.0 degrees	80.	100.
θ(t):	40. degrees	40.	5.
ϕ(t):	5. degrees	50.	150.

In addition,

$$PQ_1 = \rho_1 = 2.0 \text{ inches}$$

$$PQ_2 = \rho_2 = 1.6 \text{ inches}$$

$$PQ_3 = \rho_3 = 2.5 \text{ inches}$$

and without loss of generality, the instrumentation frame $(\hat{e}_1,\hat{e}_2,\hat{e}_3)$ was selected to coincide with the "anatomical" frame $(\hat{i},\hat{j},\hat{k})$, and the body-point for which the translational vectors will be computed, was selected to be the origin of the anatomical frame.

D.4 COMPARISON OF THEORETICAL AND COMPUTED MOTION

The 6 acceleration "readings" shown in figure 2 were analyzed. The results, shown in figures 3, 5, 7, and 9, were compared to the theoretical values and the deviations plotted in figures 4, 6, 8 and 10.

The deviations of the angular accelerations were of the order of 5.0 rad/sec^2 over magnitudes of the order of 5.0×10^4 rad/sec^2. Therefore, the accuracy of angular accelerations is of the order of 0.01%. Similar reasoning leads to determine an accuracy of 0.01% for angular velocities.

The Euler angles and rates had a relative error, or accuracy of 0.001% for rates and 0.01% for angles.

The translational accelerations had an accuracy of 0.001%, whereas both velocity and positions were accurate to within 0.1%.

From a qualitative point of view, it may be observed that the error on most of the variables increase as the integration is prolonged. This may be attributed to truncation errors in the readings that were inputted and to the round-off errors of the evaluation of natural functions and the integrals. This adds to the instability of the system of equations being integrated.

D.5 EXPERIMENTAL MOTION

The motion was experimentally generated with an electromagnetic shaker. A monkey's skull (figure 11 and 12) was instrumented with 6 accelerometers (2-2-2) combination at 3 points.

The relationship between the instrumentation origin $\underline{P}$ and reference frame $(\hat{e}_1, \hat{e}_2, \hat{e}_3)$ on one hand and the anatomical center C and reference frame $(\hat{i}, \hat{j}, \hat{k})$ on the other hand, as well as the initial orientation of the anatomical frame relative to the inertial (shaker) reference frame, were all determined with an x-ray technique developed for this purpose [1,2].

The following measurements were found:

$$\rho_1 = 2.552 \qquad \rho_2 = 2.427 \qquad \rho_3 = 2.505$$

$$\overrightarrow{CP} = 0.623\,\hat{i} - 0.459\,\hat{j} + 3.172\,\hat{k}$$

$$\begin{Bmatrix} \hat{e}_1 \\ \hat{e}_2 \\ \hat{e}_3 \end{Bmatrix} = \begin{bmatrix} -.48080 & -.59844 & -.64086 \\ -.36301 & 0.80116 & -.47578 \\ 0.79816 & 0.00389 & -.60243 \end{bmatrix} \times \begin{Bmatrix} \hat{i} \\ \hat{j} \\ \hat{k} \end{Bmatrix}$$

and the initial orientation of the anatomical frame with respect to inertial [shaker] frame:

$$\psi(0) = 2. \qquad \theta(0) = -12. \qquad \phi = -25. \text{ degrees}$$

The six accelerometers were all ENDEVCO uniaxial ones, and their signals were calibrated and amplified properly then recorded on a Honeywell 7600 FM tape recorder. The only motion variable which was directly recorded was the vertical (inertial $\hat{K}$) acceleration of the skull. This signal was to be compared to the computed component of the inertial translational acceleration of the anatomical center.

The unfiltered data, shown in figure 13, was digitized then digitally filtered using a low-pass filter. The digital filter had a pass-band from 0 to 200 Hz (gain ripple under 0.25 dB), a gain drop of -3 dB at 275 Hz, and a stop-band from 500 Hz and up, with a gain of -65 dB. The filtered data is shown in figures 14 and 15.

The rigid-body motion analysis was carried out for the 6-acceleration input and results are shown in figures 16, 17, 18, and 19.

D.6 COMPARISON OF EXPERIMENTAL AND COMPUTED MOTIONS

The only direct measurement which was made was the acceleration along the shaker vertical axis (inertial $\hat{K}$), shown in figure 14. This should be identical to the top graph of figure 18. Results show that the error in this computation was about 1.5%. It is worth noting that although no motion in the lateral (inertial $\hat{I}$ and $\hat{J}$) directions was supposed to be taking place, the computed non-zero accelerations in these directions may be attributed to small lateral vibrations of the shaker in these directions, and to unequal accuracies of calibrations of each pair of accelerometers pointing in the same direction. This error in calibration results in slightly different readings of the same acceleration, which leads to an apparent rotation. This, in turn, adds a "rotational" component to the various quantities during the computational procedure.

D.7 CONCLUSIONS

It was shown that in many cases, two of which were presented in this paper, that a 6-accelerometer technique would be useful and accurate, when physical limitations are imposed on an experiment.

The method is accurate enough for many short- and long-duration applications but the stability of the method depends largely on the accuracy of the measurements made and the type of motion being analyzed.

The truncation errors due to the finite length of a computer word and the round-off errors in evaluating numerical integrals and natural function, were found to be negligible compared to other errors.

Other errors which were found to be significant were experimental uncertainties such as the resolution of the accelerometers, their cross-axis sensitivities, mounting and orientation errors.

Additional (redundant) measurement is recommended to minimize the errors of computation and measurement, and to counter act the instability of the integration.

D.8 REFERENCES

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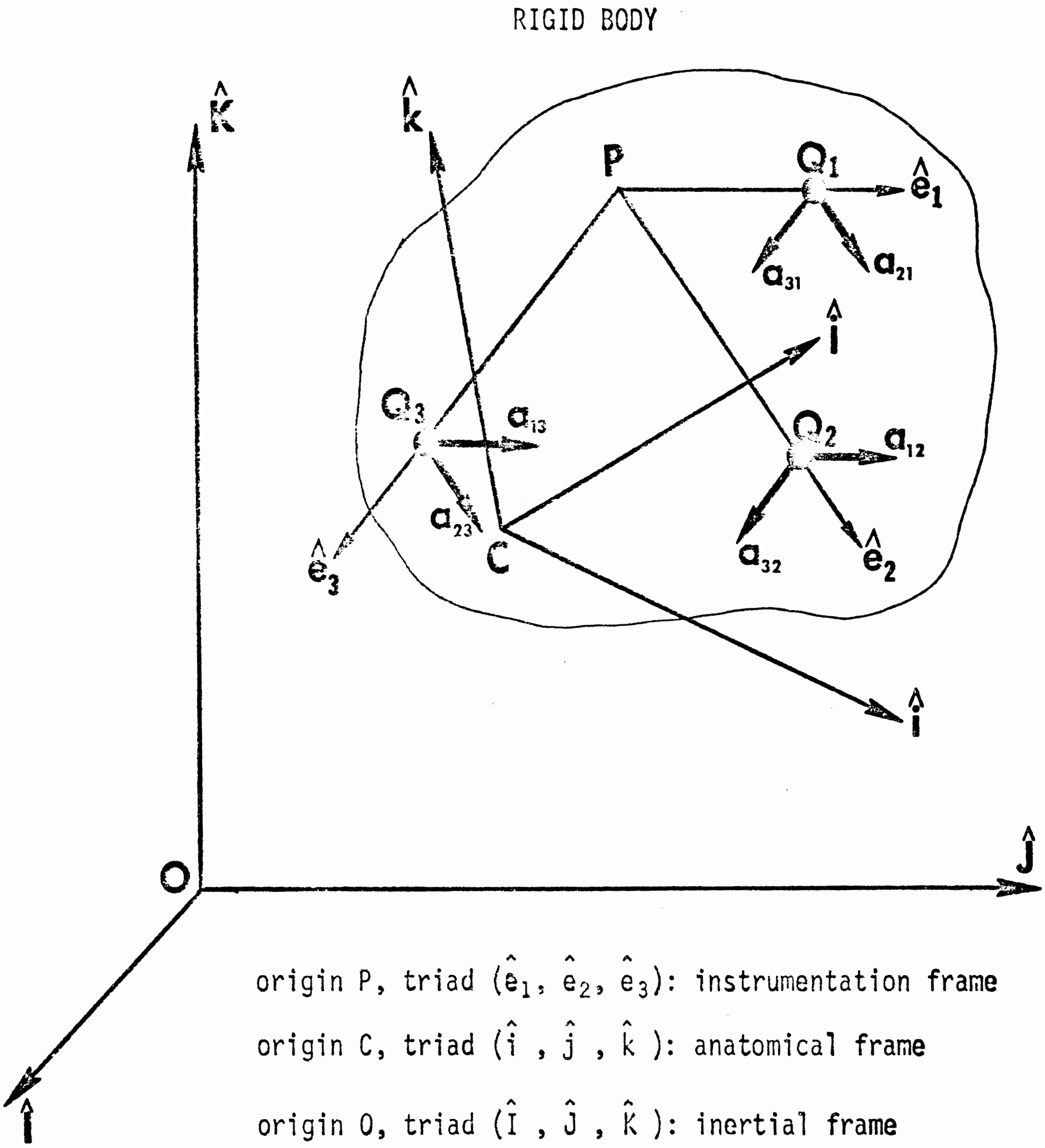
2. Melvin, J. W., J. B. Benson, and N. M. Alem, "Whole Body Response Research Program," First Year Final Report, Highway Safety Research Institute, Ann Arbor, 1975.

3. Padgaonkar, A. J., K. W. Krieger and A. I. King, "Measurement of Acceleration of Rigid Body Using Linear Accelerometers," A.S.M.E. Paper No. 75-APMB-3, 1975.



origin P, triad ($\hat{e}_1$, $\hat{e}_2$, $\hat{e}_3$): instrumentation frame

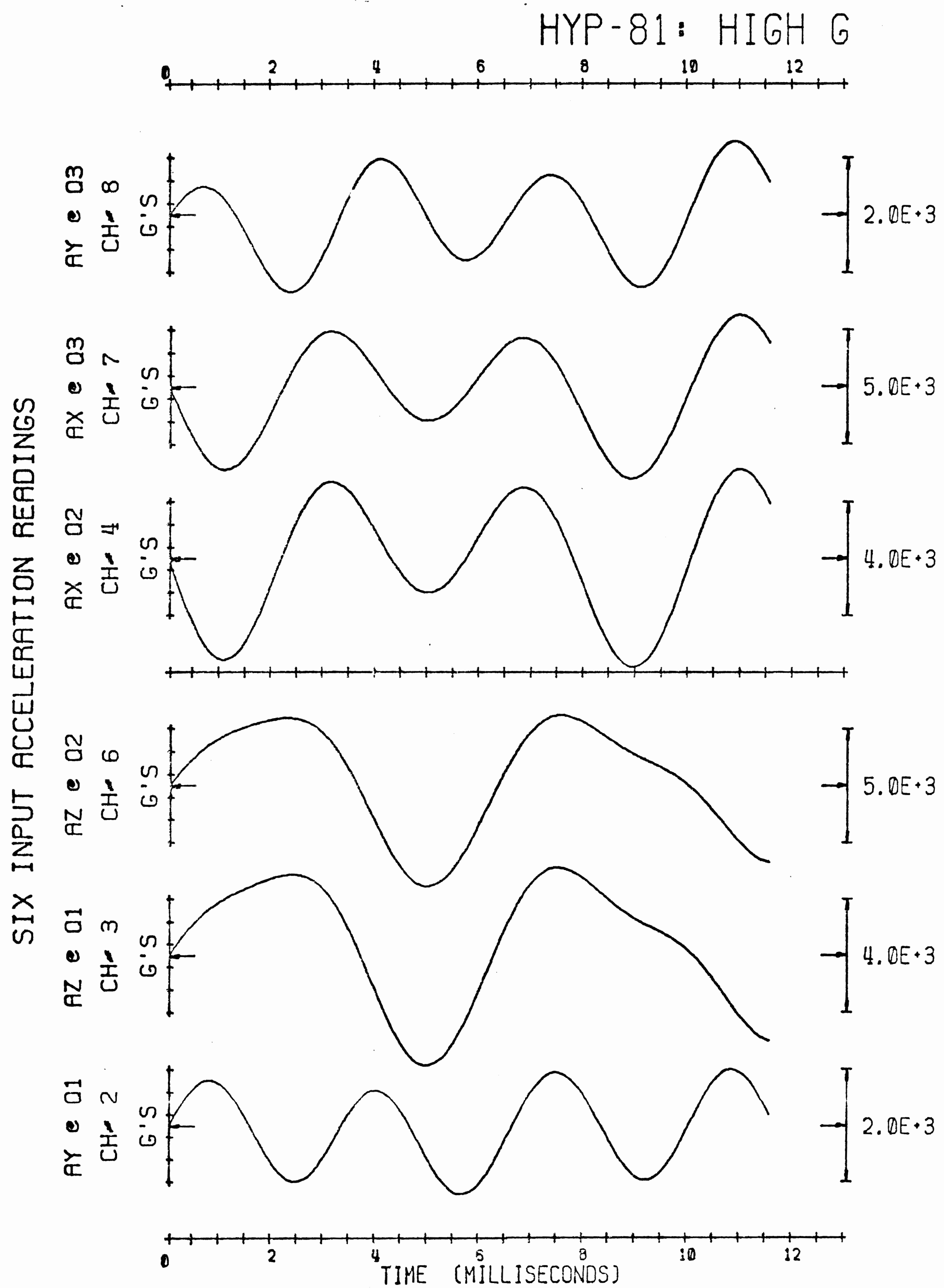
origin C, triad ($\hat{i}$, $\hat{j}$, $\hat{k}$): anatomical frame

origin O, triad ($\hat{I}$, $\hat{J}$, $\hat{K}$): inertial frame

Q_1, Q_2, Q_3: Location of three biaxial accelerometers

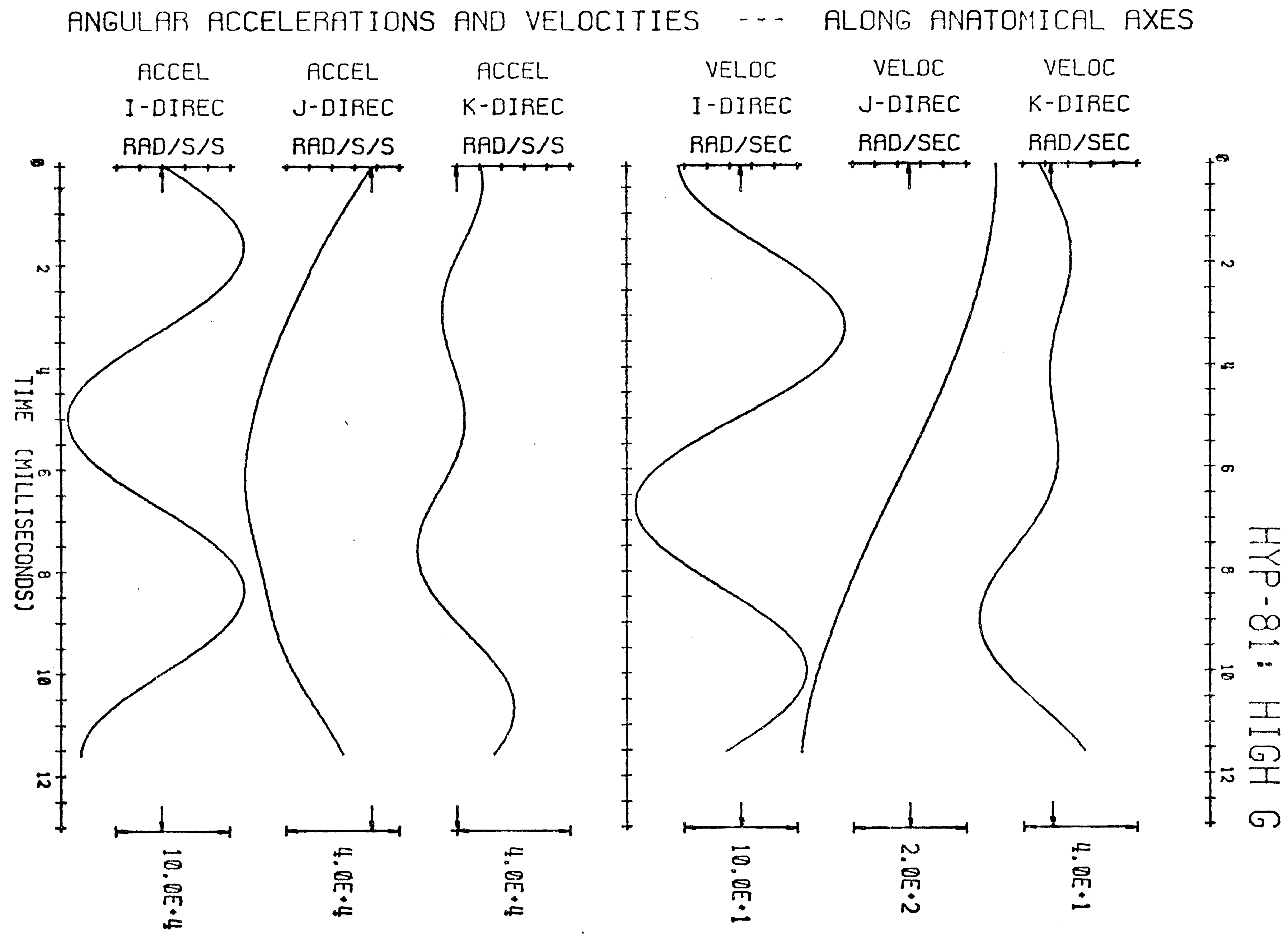
DEFINITION OF COORDINATES FRAMES FOR 3-D RIGID-BODY MOTION

Figure 1



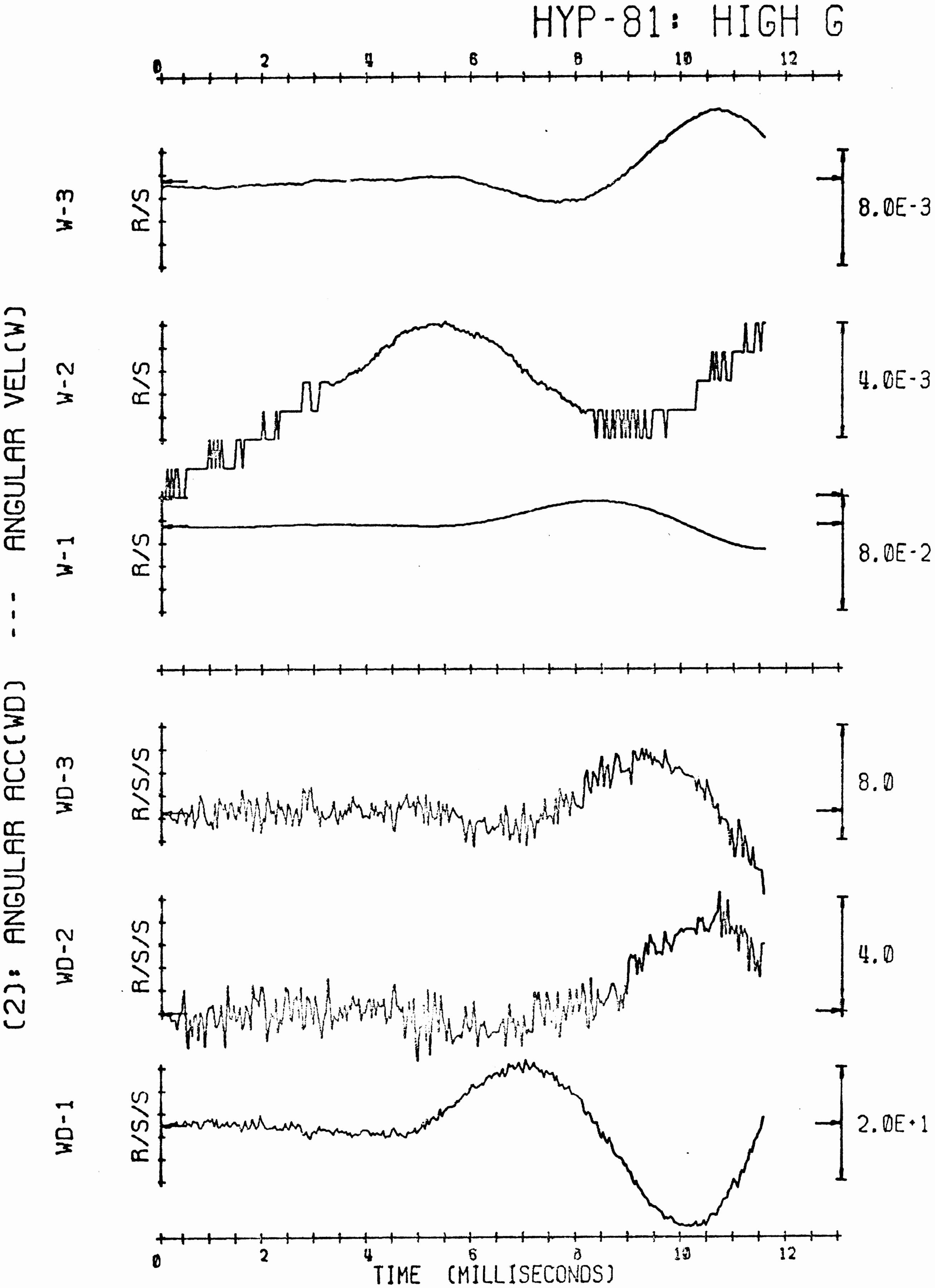
3-D RIGID BODY MOTION ANALYSIS

Figure 2



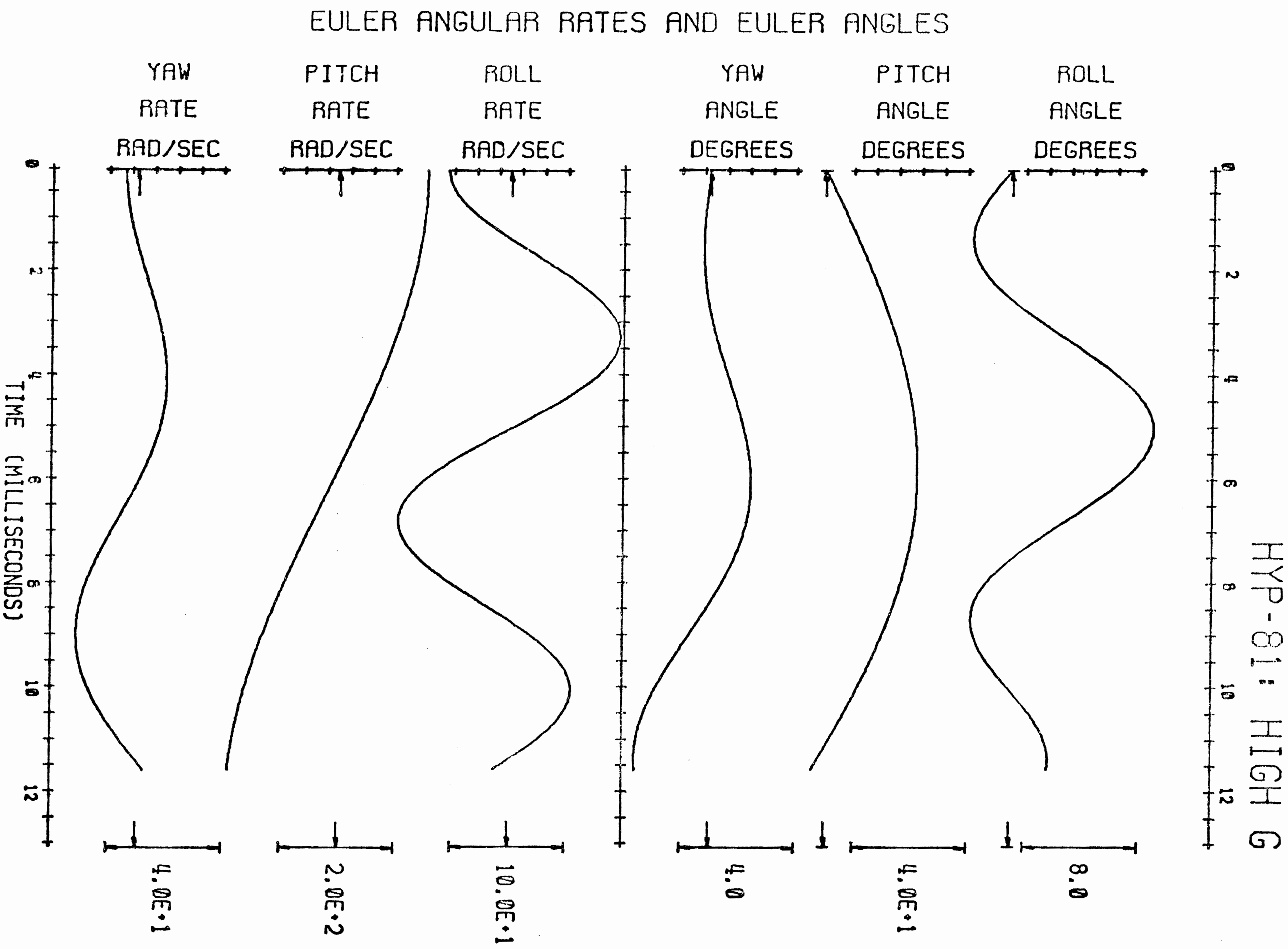
3-D RIGID BODY MOTION ANALYSIS

Figure 3



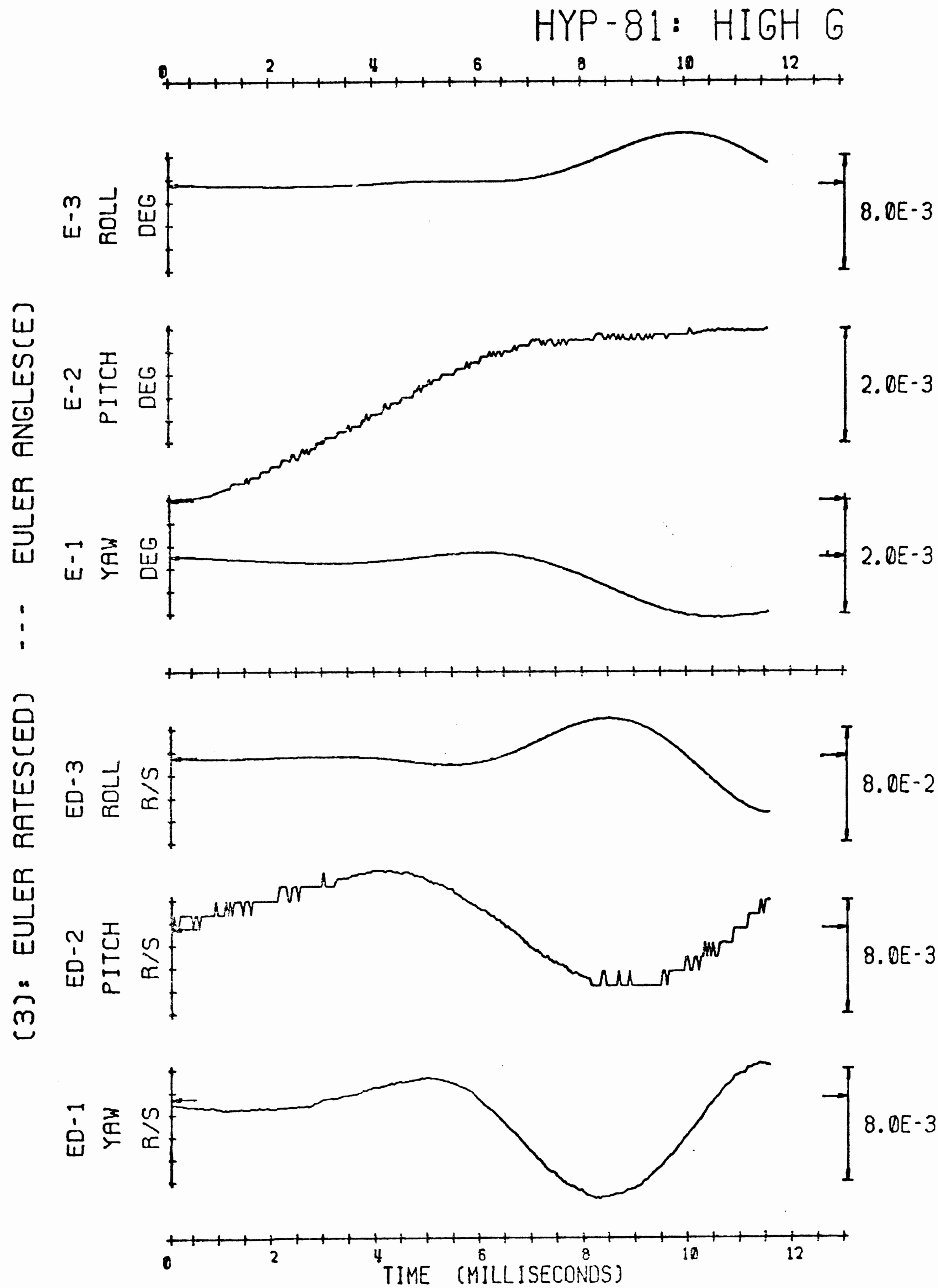
DEVIATION = ACTUAL - COMPUTED

Figure 4



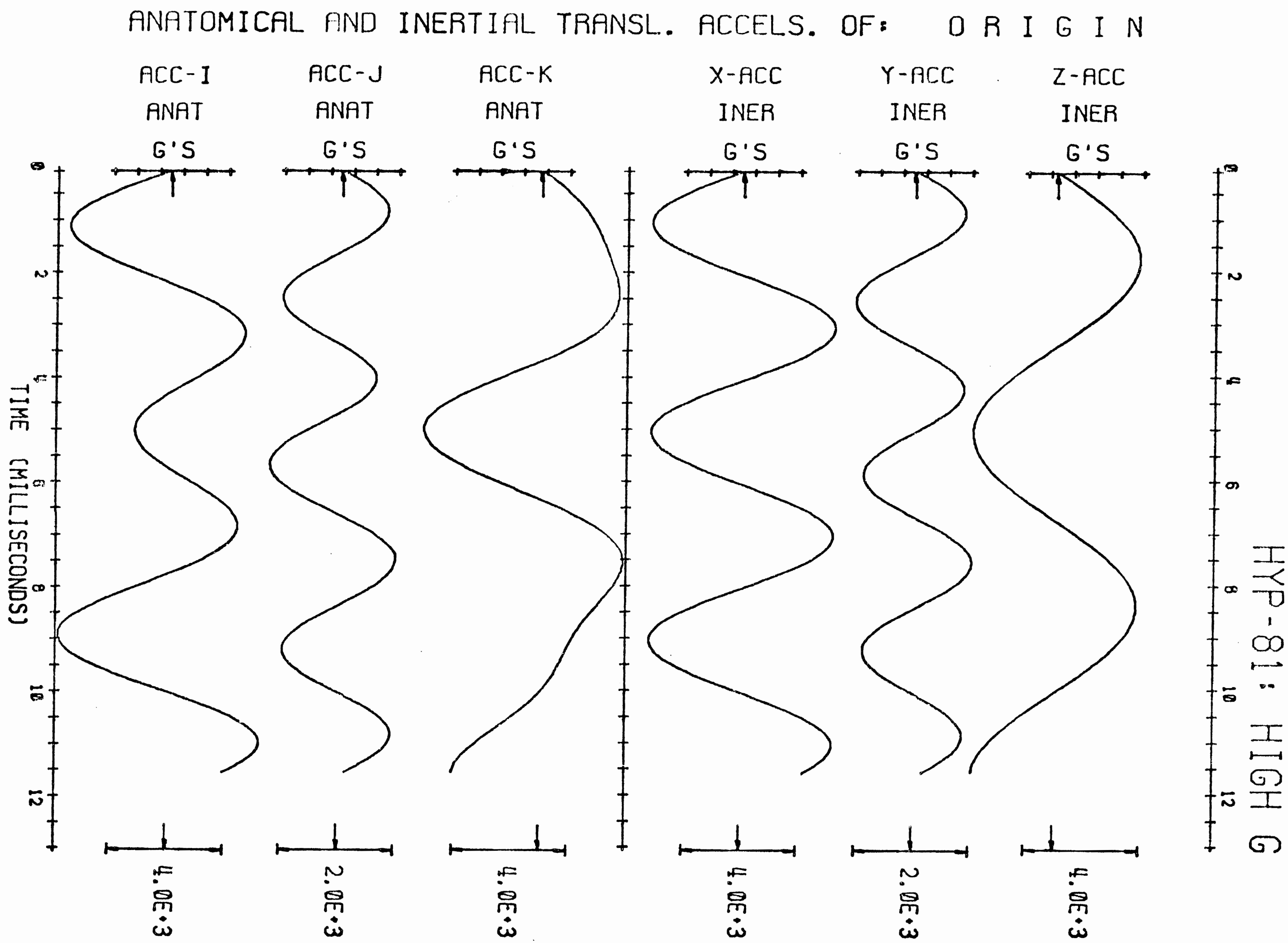
3-D RIGID BODY MOTION ANALYSIS

Figure 5



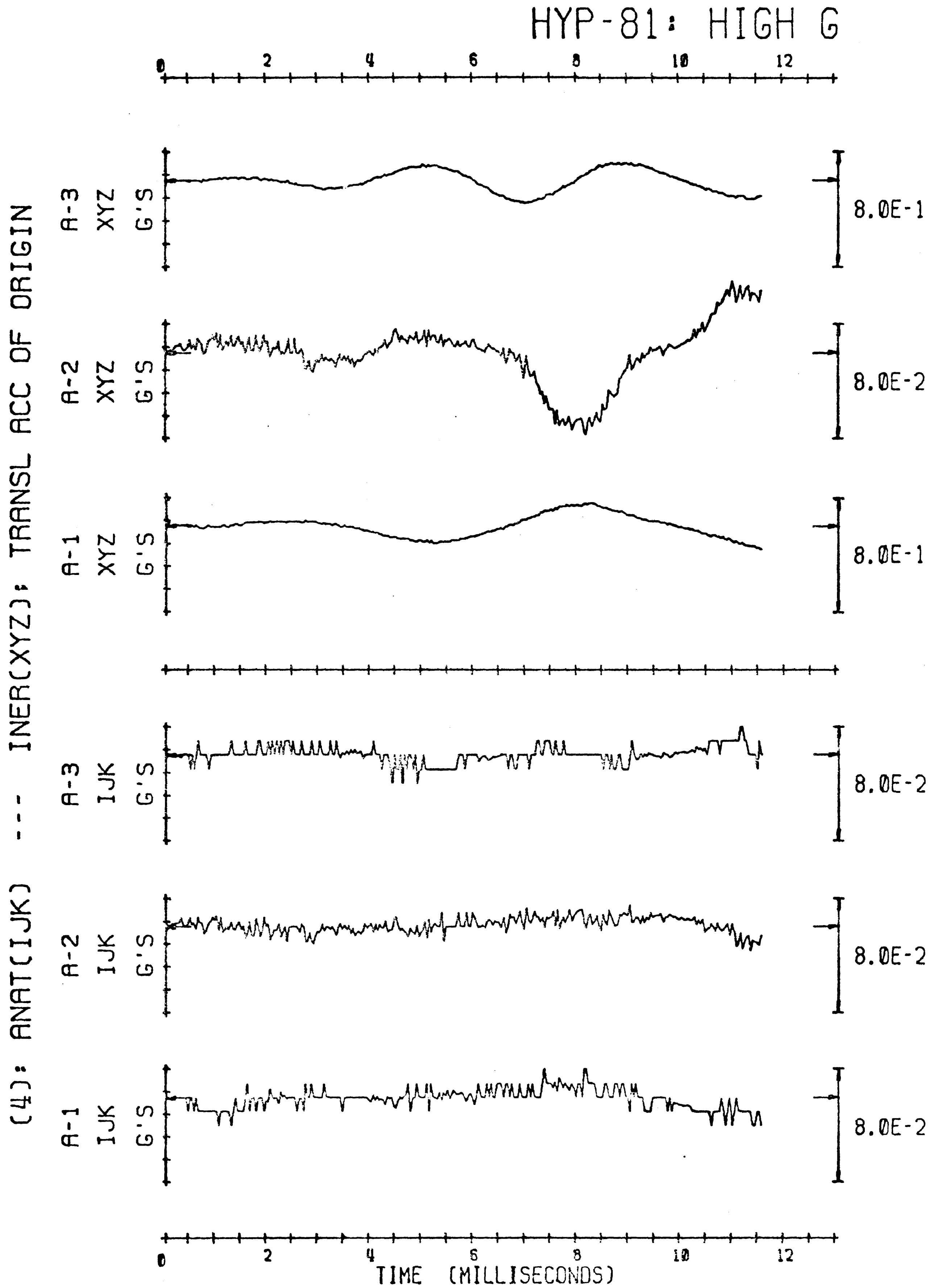
DEVIATION = ACTUAL - COMPUTED

Figure 6



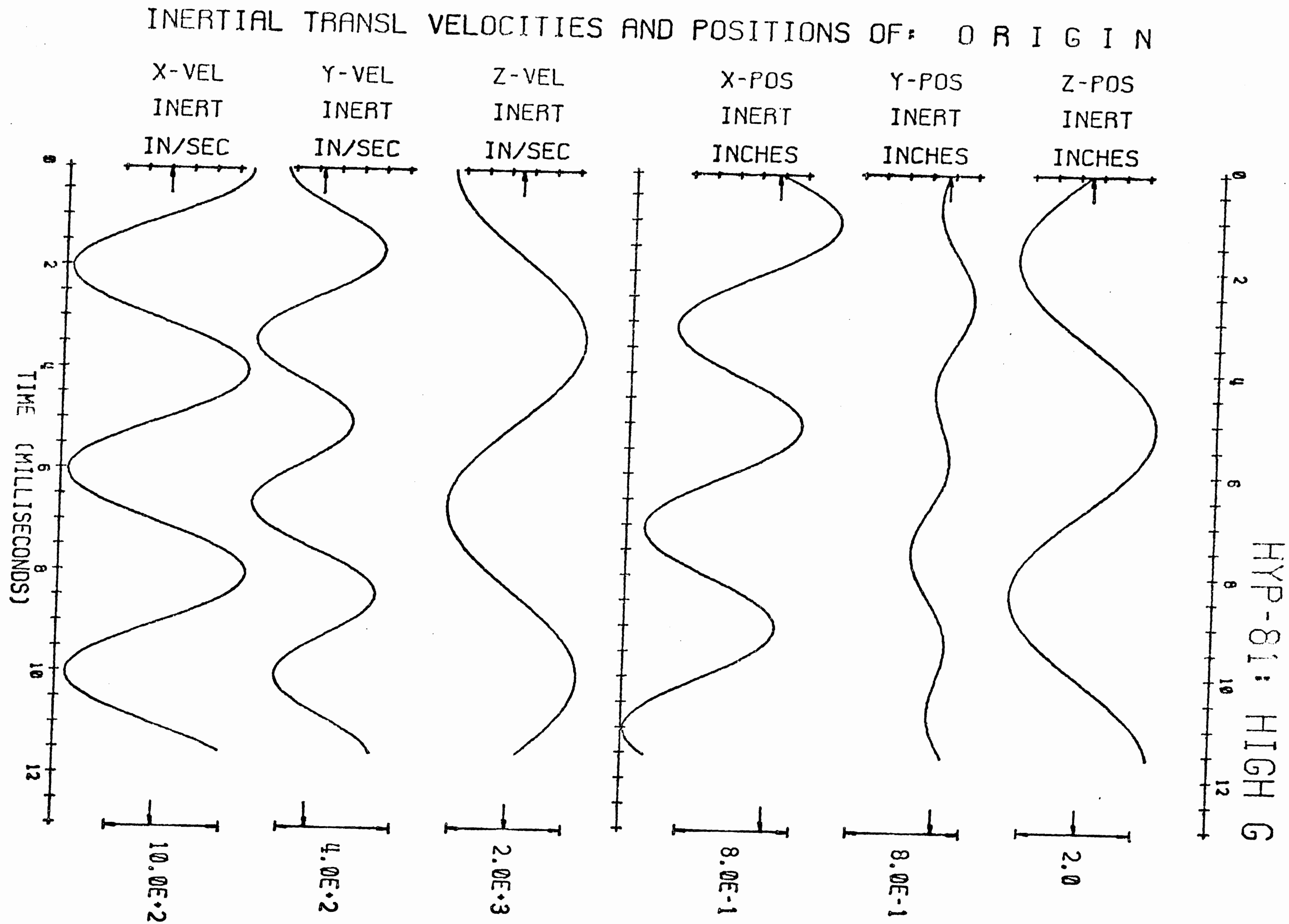
3-D RIGID BODY MOTION ANALYSIS

Figure 7



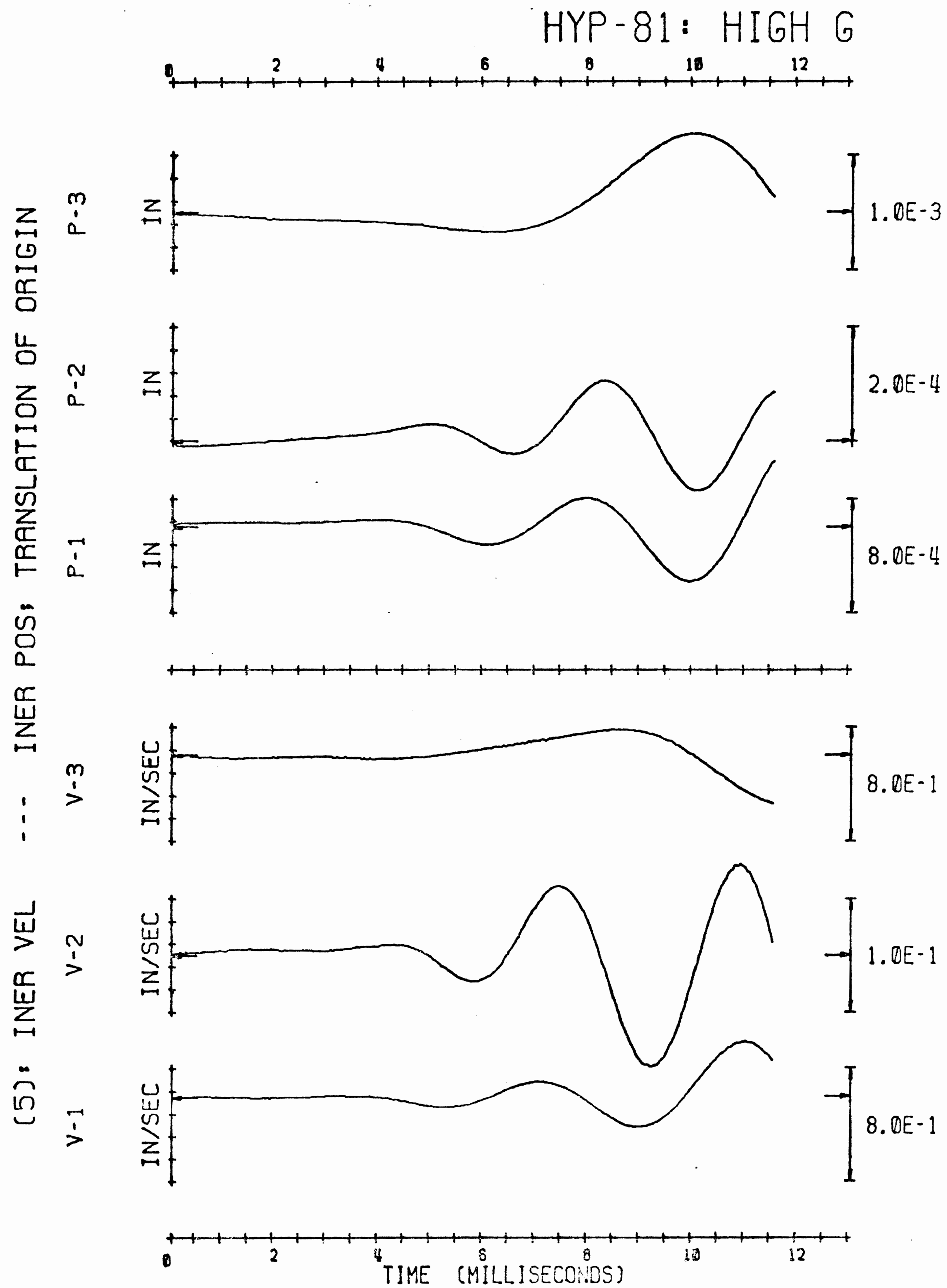
DEVIATION = ACTUAL - COMPUTED

Figure 8



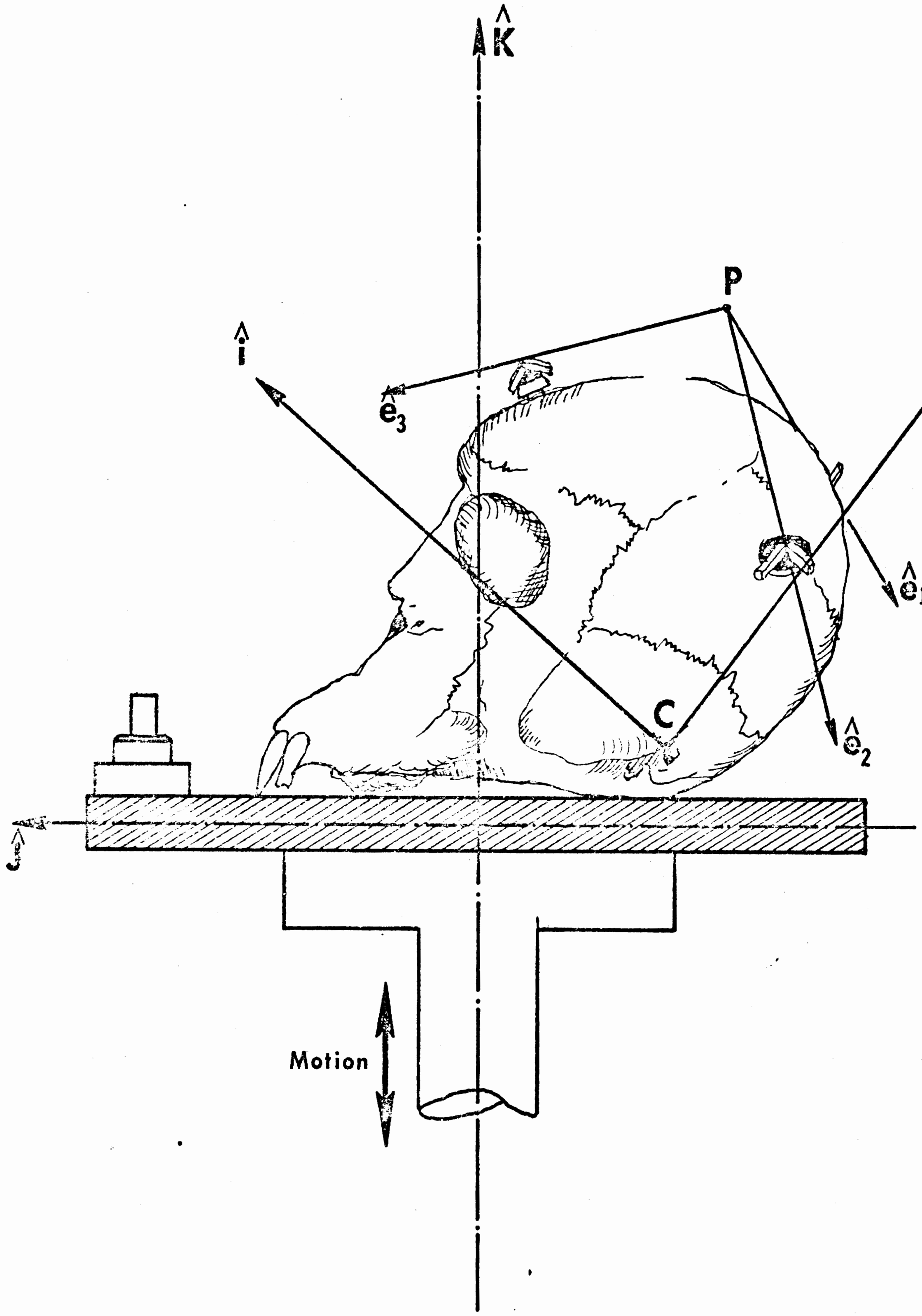
3-D RIGID BODY MOTION ANALYSIS

Figure 9



DEVIATION = ACTUAL - COMPUTED

Figure 10



SCHEMATIC DIAGRAM OF EXPERIMENTAL SET-UP FOR SKULL SHAKING.

Figure 11

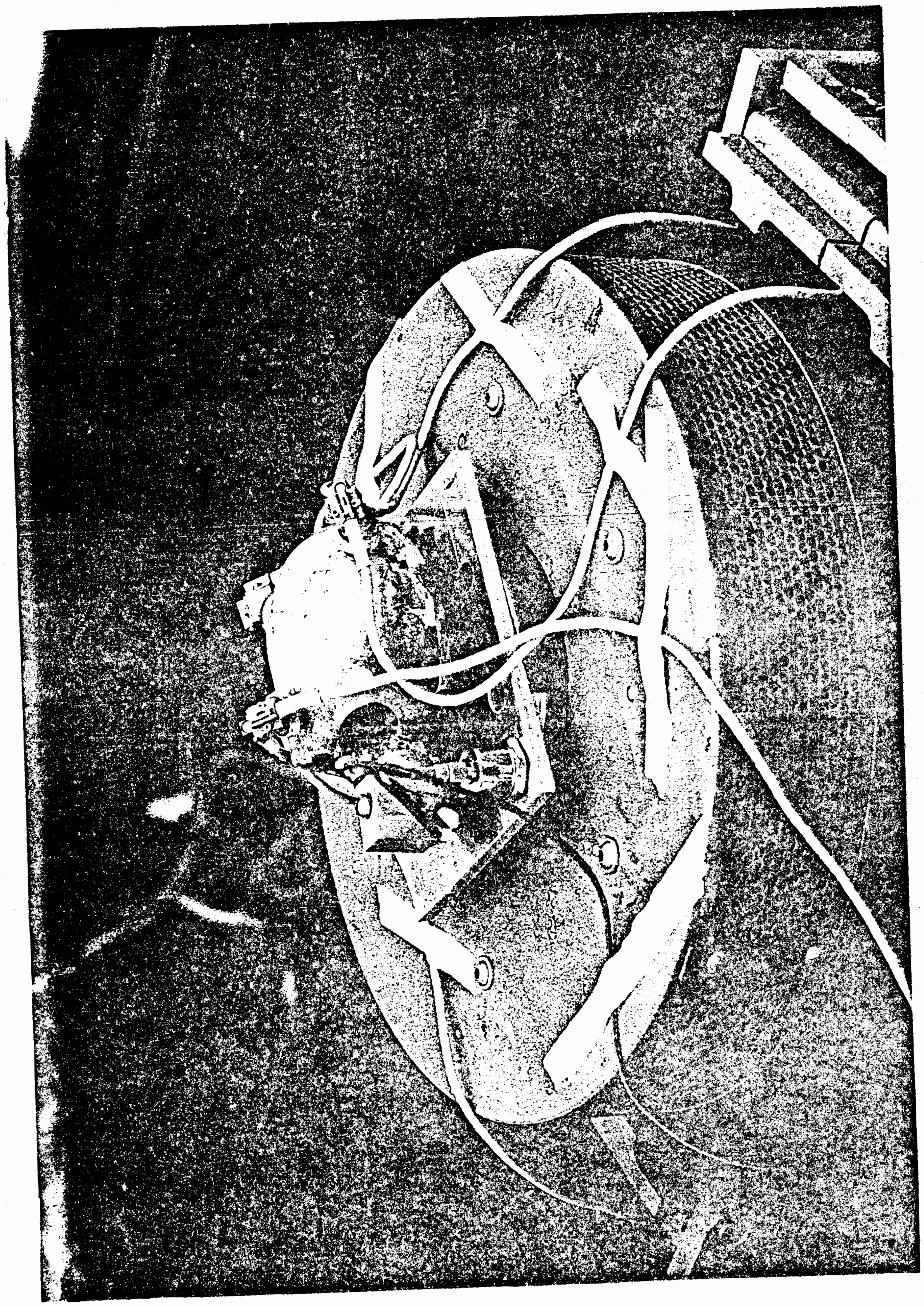


Figure 12

PTS/IN=50 SAMPLING=8468 HZ PTS=1072

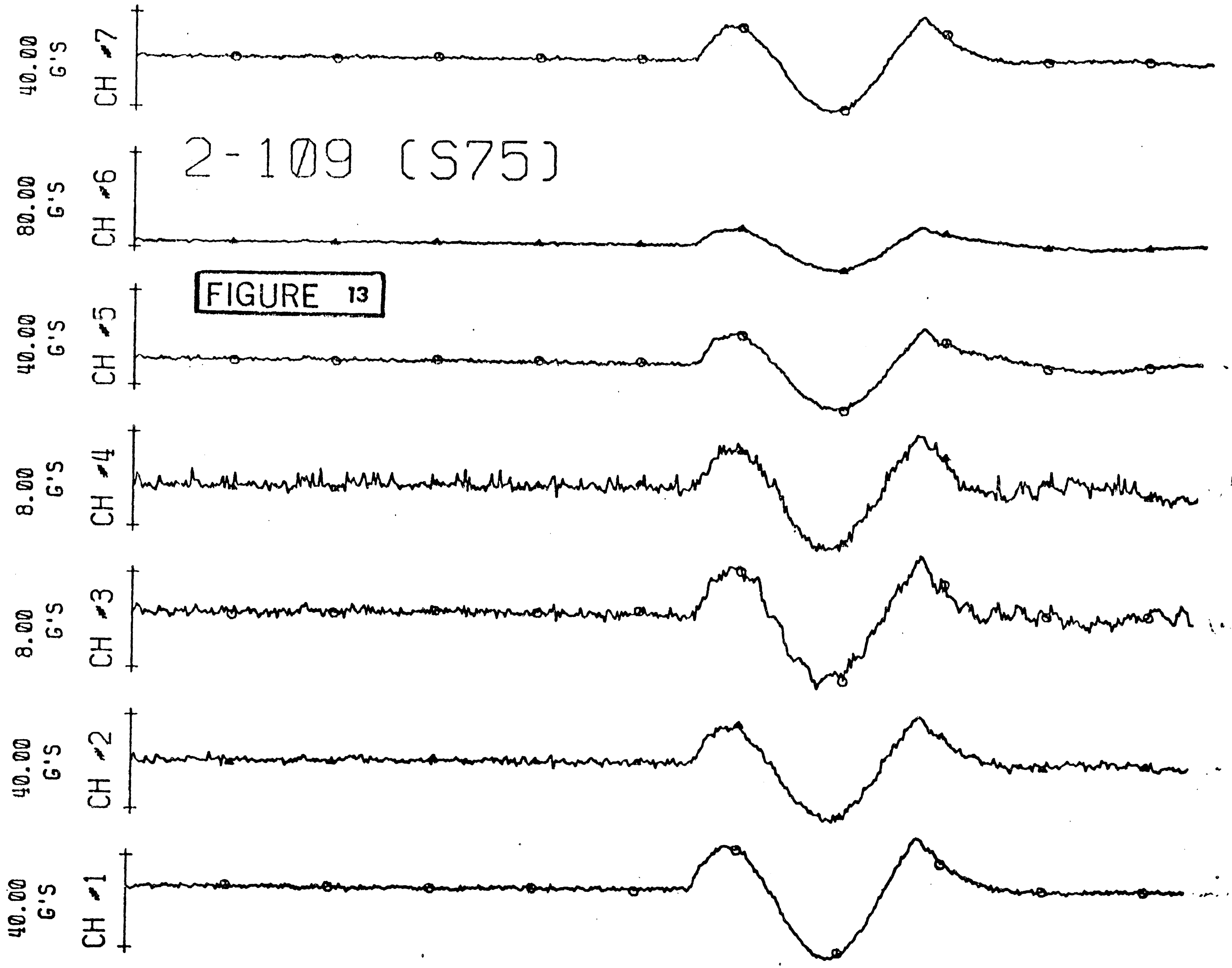


FIGURE 13

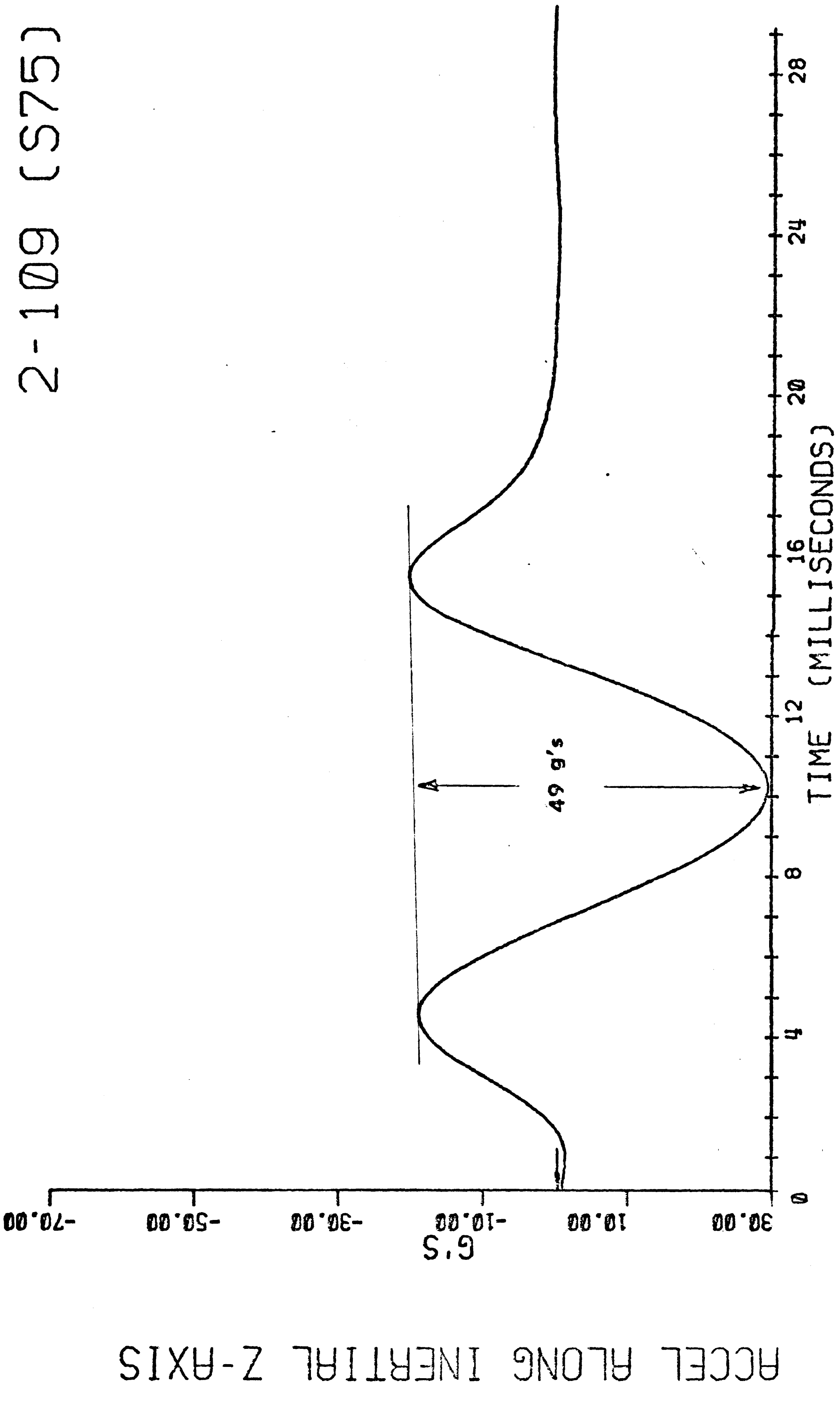
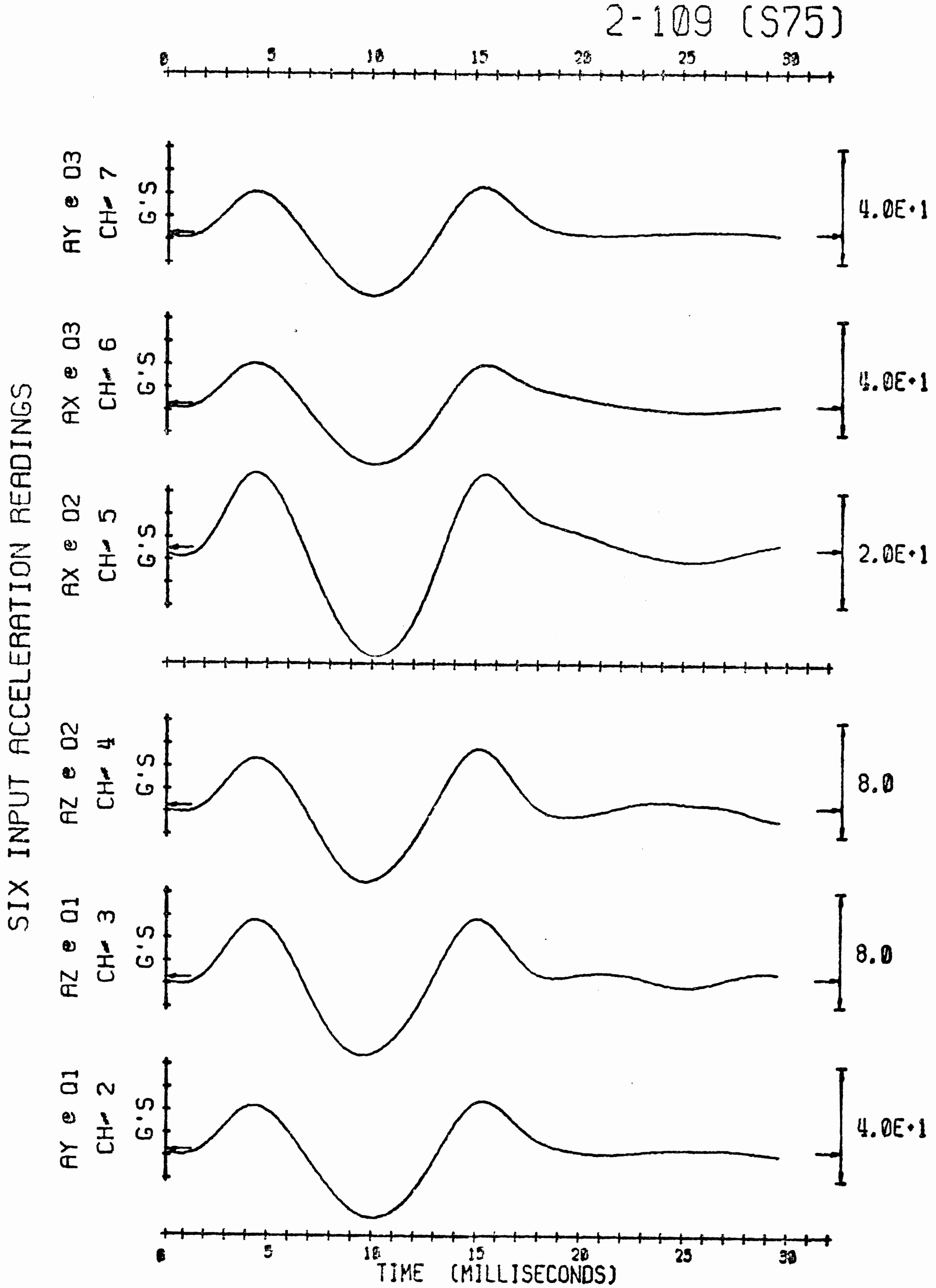
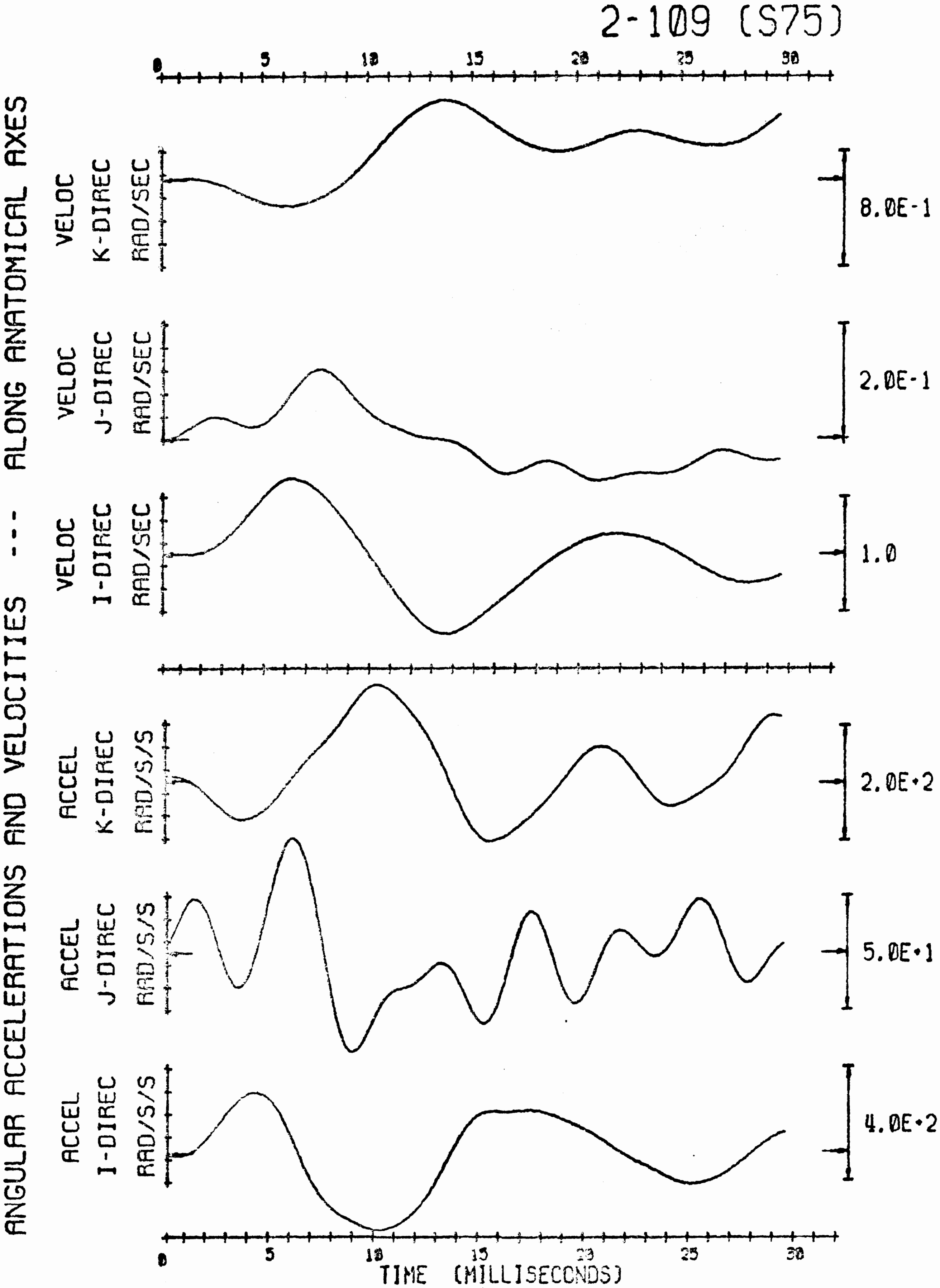

2-109 (S75)
ACCEL ALONG INERTIAL Z-AXIS
G'S
-70.00
-50.00
-30.00
-10.00
10.00
30.00
TIME (MILLISECONDS)
0
4
8
12
16
20
24
28
49 g's

Figure 14



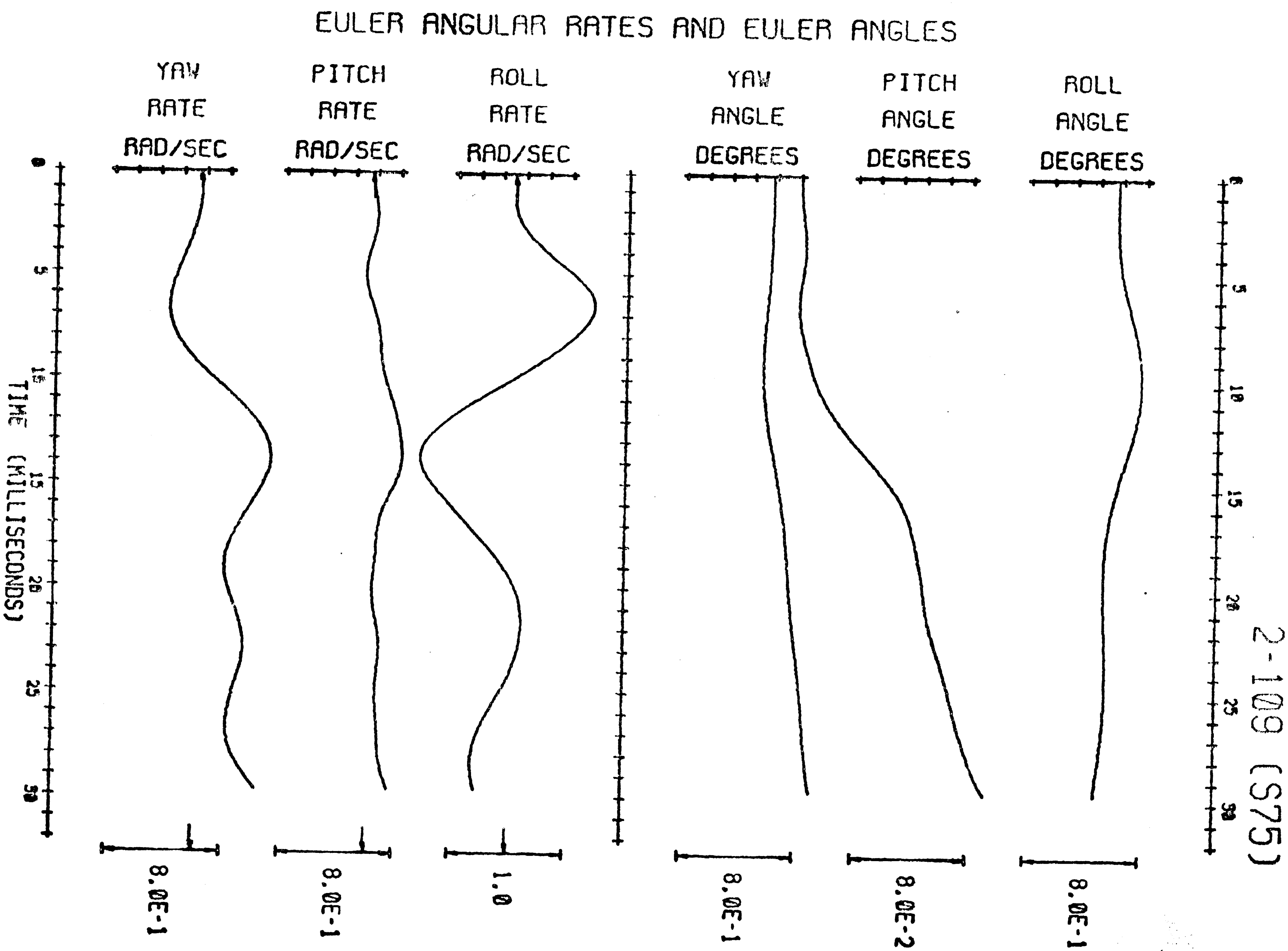
3-D RIGID BODY MOTION ANALYSIS

Figure 15



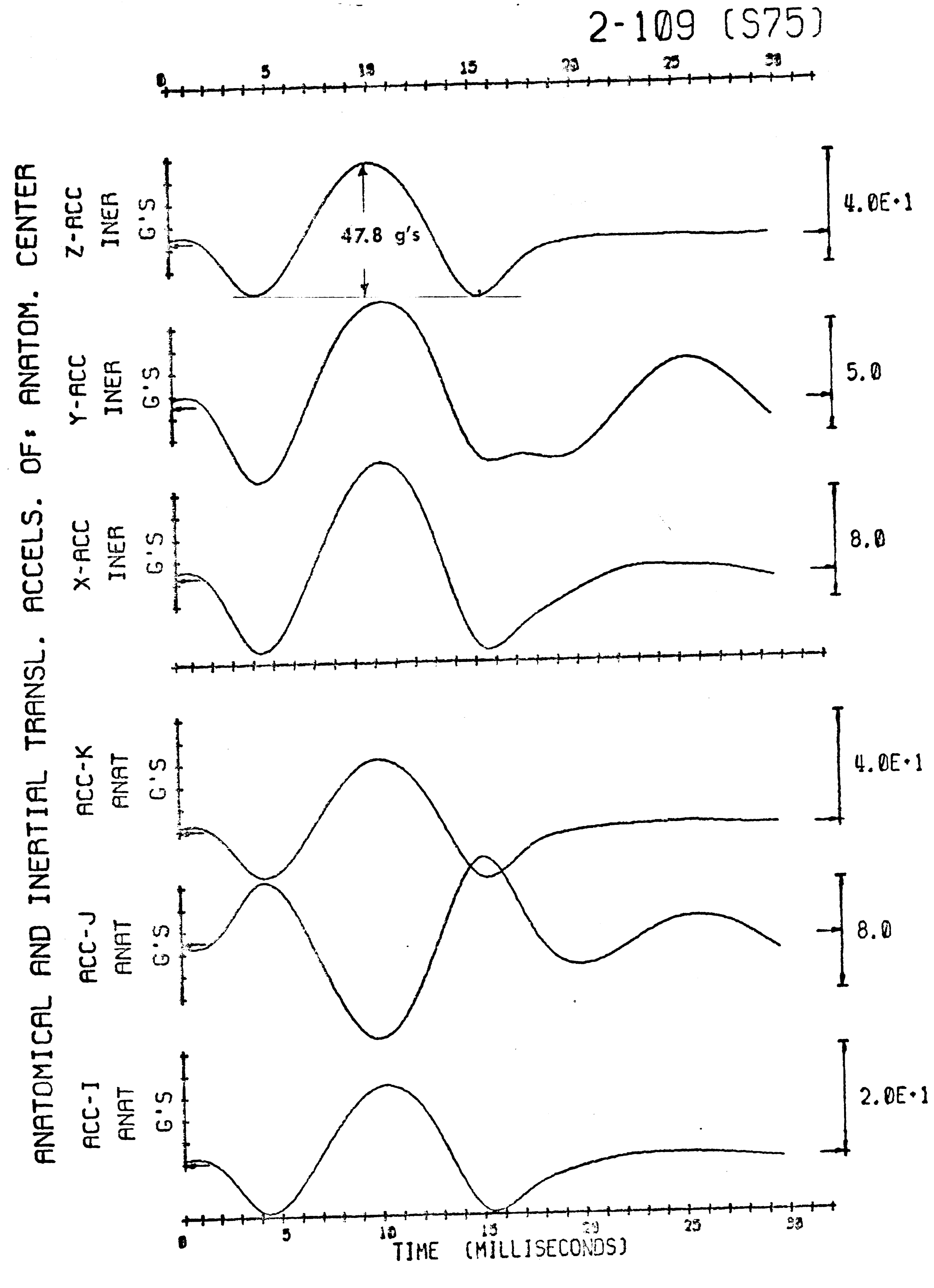
3-D RIGID BODY MOTION ANALYSIS

Figure 16



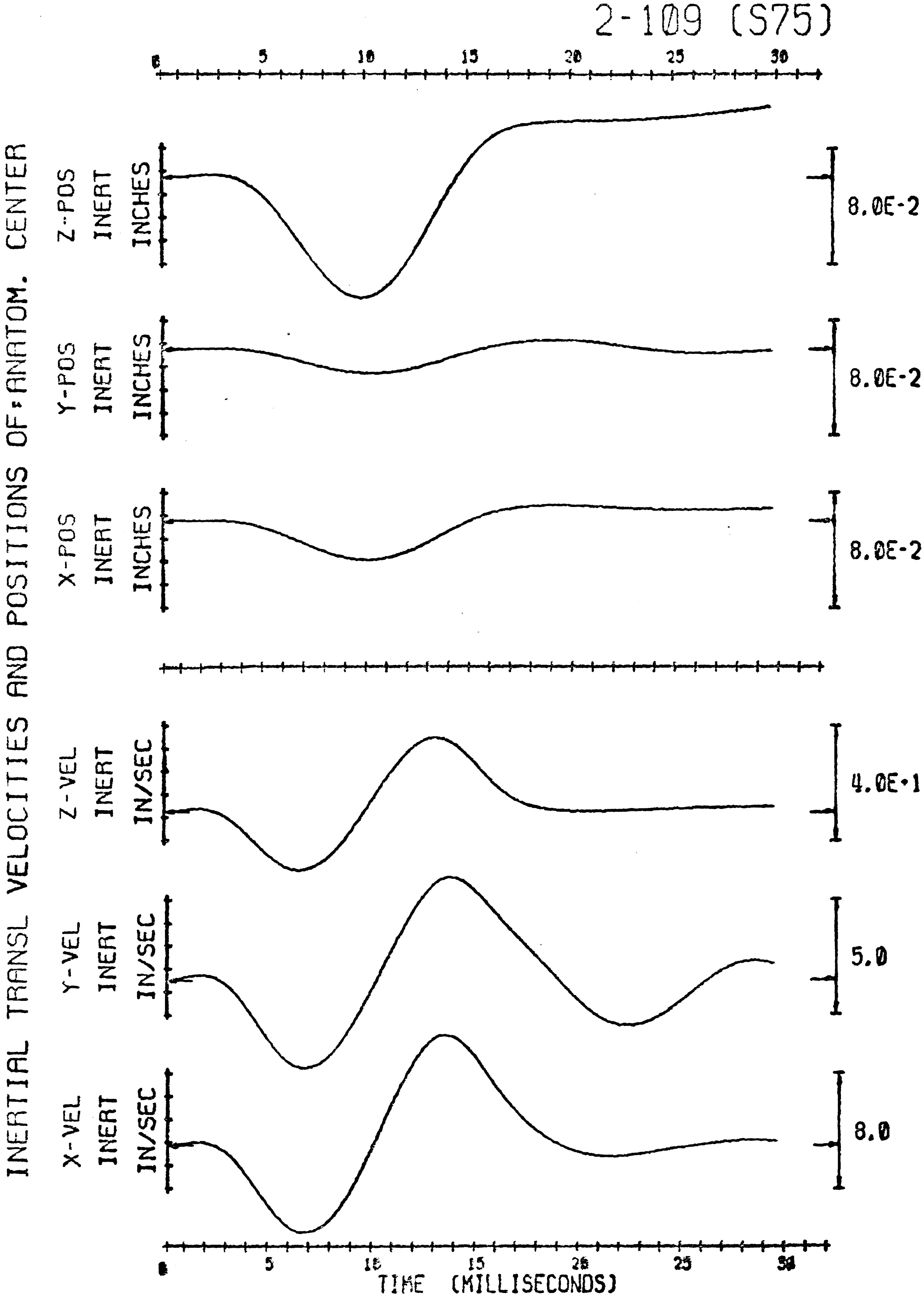
3-D RIGID BODY MOTION ANALYSIS

Figure 17



3-D RIGID BODY MOTION ANALYSIS

FIGURE 18



3-D RIGID BODY MOTION ANALYSIS

FIGURE 19

APPENDIX E

DIGITAL SIGNAL PROCESSING

APPENDIX E: DIGITAL SIGNAL PROCESSING

E.1 Analog-to-Digital Conversion

A general-purpose PDP-11/45 computer, with a 16-channel A/D unit is currently used at HSRI to convert all analog signals into digital form. Since this computer is not dedicated to A/D conversion, its real-time sampling rate is about 125 Hz, which is much lower than the requirements of biomechanical measurements, where events can be as brief as a few milliseconds.

Sampling rate may be increased by playing back the analog tape at a speed lower than the one at which it was recorded. Thus, if a tape was recorded at 30 ips during the experiment, and played back at 1 7/8 ips during digitizing, the sampling rate is multiplied 16 times, resulting in a sampling rate of about 2.0 kHz.

However, in most applications, this sampling rate may not be sufficient. In this case, either a faster digitizing hardware is required, or a further expansion of time is necessary. The latter can simply be accomplished by re-recording the analog signal at a speed higher than the speed intended for playback. Thus, an analog tape, originally recorded at 30 ips, can be played back at 1 7/8 ips into another recorder, which will re-record the expanded signal at 30 ips. This last recording is played back at 1 7/8 ips during digitizing, resulting finally in a sampling rate of 32. kHz, which is 16 times higher than previously obtained.

The user has the option of reducing the sampling rate by as much as he desires. This is done by selecting, say every 8th point, to be saved, thus reducing the maximum rate of 32 kHz by a factor of 8, resulting in a final sampling rate of about 4 kHz.

The selected samples of data are converted into physical units, and saved on a digital magnetic tape, each channel in a separate file, along with a unique run identification, a description of the contents and the units, the sampling rate and the number of resulting points.

E.1.1 The Sampling Process

The operation of sampling can be viewed as a form of impulse modulation. Accordingly, if an analog signal is sampled at the rate of f_s(Hz), i.e., at intervals of $T = 1/f_s$ seconds, then the sampled signal $x^*(t)$ may be represented as a train of impulses given by:

$$x^*(t) = T \sum_{n=0}^{\infty} x(nt)\delta(t-nT) \qquad (1)$$

where $x(t) = 0 \quad \text{for } t < 0$

$\delta(t) = 1 \quad \text{for } t = nT$

$\delta(t) = 0 \quad \text{for } t \neq nT.$

The digital signal $x^*(t)$ is not a continuous function of time, but a sequence of numbers, taken as the values of $x(t)$ at $t = nT$. The z-transform of equation (1) is

$$X^*(z) = T \sum_{n=0}^{\infty} x(nT)z^{-n} \qquad (2)$$

The original signal $x(t)$ can be recovered by passing $x^*(t)$ through an ideal low-pass filter of bandwidth $\pm f_s/2$. The recovery is exact only if the Fourier transform of $x(t)$ is identically zero outside the central strip $\pm f_s/2$. This band is called the Nyquist band, and $f_s/2$ is called the Nyquist rate, which is half the sampling rate.

E.1.2 The Sampling Theorem

> If a signal $x(t)$ has a Fourier transform that identically zero for $|f| \geq B$, it can be completely reconstructed from samples taken at the rate of $f_s \geq 2B$.

The implications of this theorem is that if we sample at a rate $f_s = 1/T$, with f_s sufficiently faster than the Nyquist rate, then we can retrieve the original $x(t)$ by the use of the ideal interpolation operator, which has an impulse response:

$$p(t,n) = \frac{\sin\left[\frac{\pi}{T}(t-nT)\right]}{\frac{\pi}{T}(t-nT)}, \qquad (3)$$

then the recovered signal $x_0(t)$ is given by

$$x_0(t) = \sum_{n=0}^{\infty} x(nT)p(t,n). \qquad (4)$$

Again, $x_0(t)$ will be identical to $x(t)$ only if the analog $x(t)$ is band-limited to the Nyquist band, i.e., if $x(t)$ contained no frequencies higher than half the sampling rate.

To guarantee this, the analog signals may be electronically filtered prior to the A/D conversion process, thus eliminating all frequencies above the Nyquist frequency. If analog filters are to be avoided altogether, then the sampling rate must be sufficiently faster than any suspected frequency component in the analog signal. In rigid body motion measurements, frequencies of interest are well below 500 Hz, thus, a sampling of 2000 Hz is quite sufficient, unless noise frequency are above the Nyquist rate of 1000 Hz.

E.2 Signal Filtering

The presence of high-frequency components in the digital signals is undesirable. These components are usually noises or mechanical resonances of transducers which are not relevant to the physical quantity being measured. To eliminate these components, analog filtering may be employed. However, the cut-off frequencies must change depending on the signal being measured. Sophisticated analog filters are expensive, and usually have a fixed cut-off frequency. Variable filters of equal sophistication are large and bulky, so that the only alternative is digital filtering.

E.2.1 Digital Filters

Just like analog filters, digital filters have input-output response, but they can be "constructed" at a much lower cost, and are just as easy to use.

The output/input transfer function of a general linear system may be transformed to a digital transfer function of the form:

$$H^*(z) = \frac{\sum_{j=0}^{N-1} a_j z^{-j}}{1 + \sum_{j=1}^{N} b_j z^{-j}} \tag{5}$$

Equation (5) is used to compute the current value of the output y(nT), given current value of the input x(nT) and previous values of the input and output:

$$y(kT) = \sum_{j=0}^{N-1} a_j x(kT-jT) - \sum_{j=1}^{N} b_j y(kT-jT) \tag{6}$$

The order N of the filter must be finite in order to reconstruct the signal. Furthermore, the data is reconstructed using a finite number of impulse responses, hence the term finite duration impulse response (FIR) filter.

The case where all the b-coefficients in equation (5) are zero reduce the transfer function to:

$$H^*(z) = \sum_{j=0}^{N-1} a_j z^{-j}. \qquad (7)$$

The filter is then classified as a non-recursive digital filter, since it does not use previous values of the output, as can be seen from equation (6) with only the a-coefficients.

E.2.2 FIR Filter Design

Any finite-duration sequence is completely specified by N samples of its Fourier transform, so that the design of an FIR filter may be accomplished by finding N coefficients of its impulse response. The truncation of the infinite duration impulse response of the first N terms means that discontinuities at the corner-frequencies are replaced by smoother transitions. Accompanying this transition is some under- and over-shoots which are generally described as the Gibbs phenomenon.

The frequency response of an FIR filter is no longer flat in its pass- and stop-bands, but contains some ripples which vary in magnitudes depending on the design characteristics of the filter. These ripples may be spread uniformly over the frequency spectrum, resulting in an equiripple design. For a given filter length N, and a given set of corner (edge) frequencies and band gains, an optimum filter becomes one which has the minimum peak-to-peak ripple.

The Alternation theorem (Parks & McClellan, 1970) is the basis for finding such optimum filters. Essentially, this theorem implies that there is a precise number of frequencies corresponding to peaks in the error function describing the ripples in the magnitude frequency response.

Armed with this theorem, an optimum filter may be found by searching (on the frequency axis) for the "best" extremal frequencies, i.e., those for which the ripples satisfy a specified tolerance.

Subsequently, McClellan & Parks (1973) published a paper in which they present a general purpose computer program which is capable of designing a large class of optimum non-recursive linear-phase FIR digital filters. The search algorithm is based on the Remez exchange method, which is a fast method to approximate an ideal frequency response using the minimum weighted Chebychev error. The program replaces the specified design by an equivalent problem, then solves the approximation of the equivalent problem using the Remez exchange method, then produces, among others, the filter impulse response.

The program now used at HSRI to design digital filters is based on the McClellan design program. However, it is an interactive program, where a user can use a terminal to design, test, check frequency response and save, if he so desires, the impulse response of an acceptable filter on a master file containing all the filters designed up to date. This master file is effectively a "storage shelf" for all the digital filters, and when a filter is needed, it is either pulled out of the "shelf," or a new filter is designed and saved, if none of the available filters fits the requirements.

E.2.3 The Filtering Operation

An FIR digital filter of Length L, is specified by M terms of its impulse response:

$$h(m); \qquad m = 1, 2, \ldots M,$$

The impulse response is symmetric, i.e.,

$$h(1+k) = h(M-k); \qquad k = 1, L. \tag{8}$$

Given then a finite number M terms of its impulse response, and given a digital signal specified as a sequence of N values:

$$x(n); \qquad n = 1,2, \ldots\ldots N,$$

the filtered signal is given by

$$y(n) = \sum_{k=1}^{M} x(n-k)\, h(k) \tag{9}$$

Note that the furthest point of the unfiltered signal which can be used is $x(n-M)$ which cannot be smaller than $x(1)$; therefore, the first filtered point is $y(M+1)$. This also implies that the digital signal must have at least M points to produce at least 1 filtered point. Furthermore, the last filtered point which may be produced is $y(n+1)$, by using the last M points of the unfiltered signal. This results in an output signal which is shorter than the input signal, and which is phase shifted with respect to the input signal.

The first problem may be solved by extending the input signal below the first point. This is done by rotating the signal 180 degrees about the first point. Thus:

$$x(1-k) - x(k) = -[x(1+k) - x(1)]$$

or $$x(1-k) = 2x(1) - x(1+k) \tag{10}$$

The extension is carried out until enough points are generated to produce $y(1)$, i.e., $k = 1,2, \ldots (M-1)$.

The time delay problem is inherent in non-recursive filters. However, this problem can be solved either by making a correction in the phase when the phase frequency-response is known, or by using the filter itself to shift back the signal by the same amount.

The latter method of filtering forward, then filtering backwards is an outstanding method, since in general, each component is shifted by an amount depending on its frequency. Because the frequency content of a given signal is not known a priori, each component which the filter passes is phase-shifted during the forward operation, but it is shifted back by exactly the same amount during the backward operation.

However, for the backward filtering operation, the first point generated is the (N-M)th point, leaving the last M points unprocessed. In order to be able to obtain the N-th point of the signal in a filtered form, the input signal must be extended (M-1) points beyond the last point, much the same way the extension was done for the beginning of the signal. Thus:

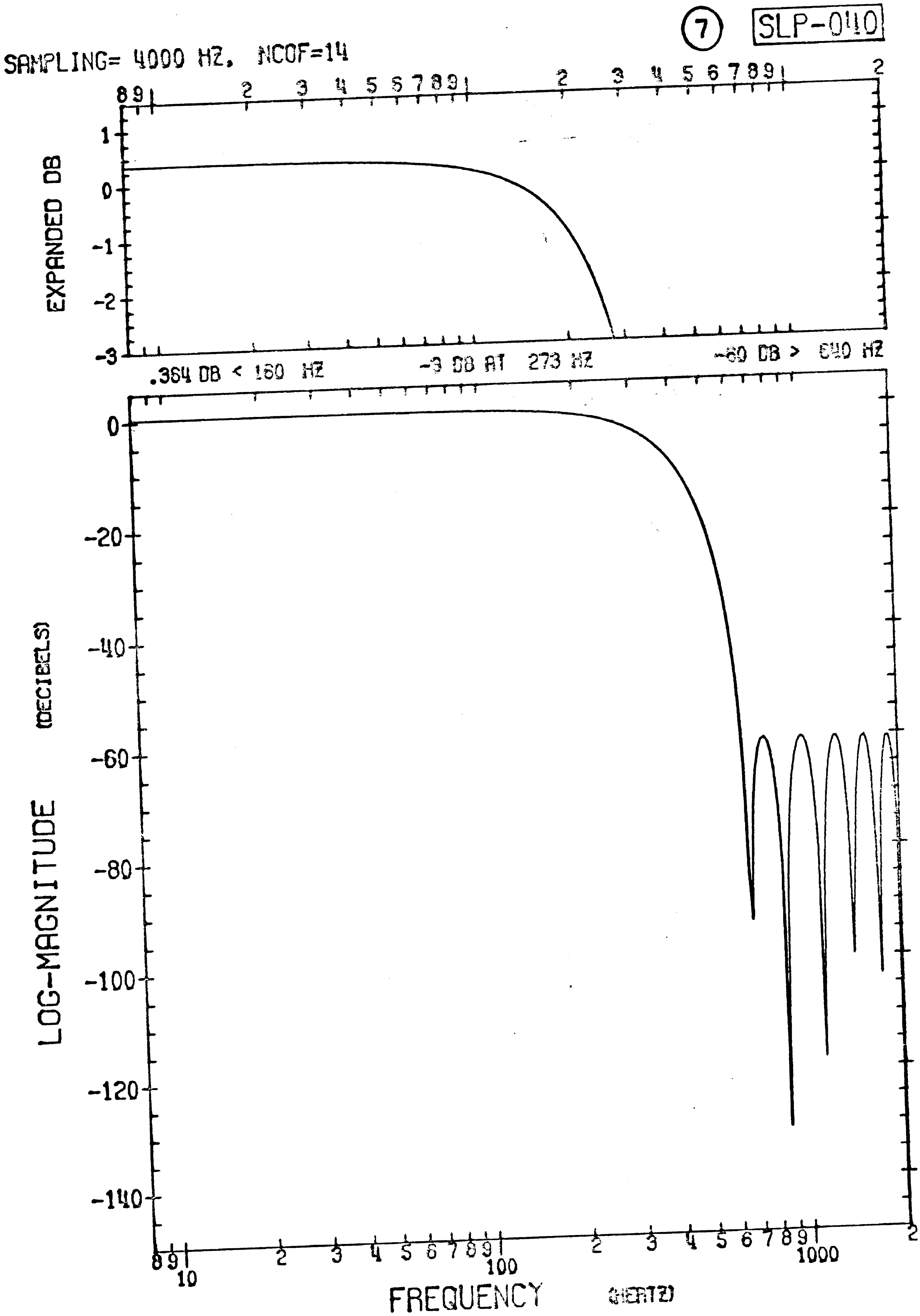
$$x(N+k) - x(N) = -[x(N-k) - x(N)]$$

or $$x(N+k) = 2x(N) - x(N-k). \tag{11}$$

with $k = 1, 2, \ldots. (M-1)$.

In this forward/backward operation, the gains of the various bands are doubled. For example, a low-pass filter with a pass-band ripple of ±0.1 dB and a stop-band gain of -65 dB and a considerable phase-shift, effectively becomes a filter with a pass-band ripple of ±0.2 dB which is still excellent, a stop-band gain of -130 dB, which surpasses any stringent design specification, and best of all, it becomes phase transparent.

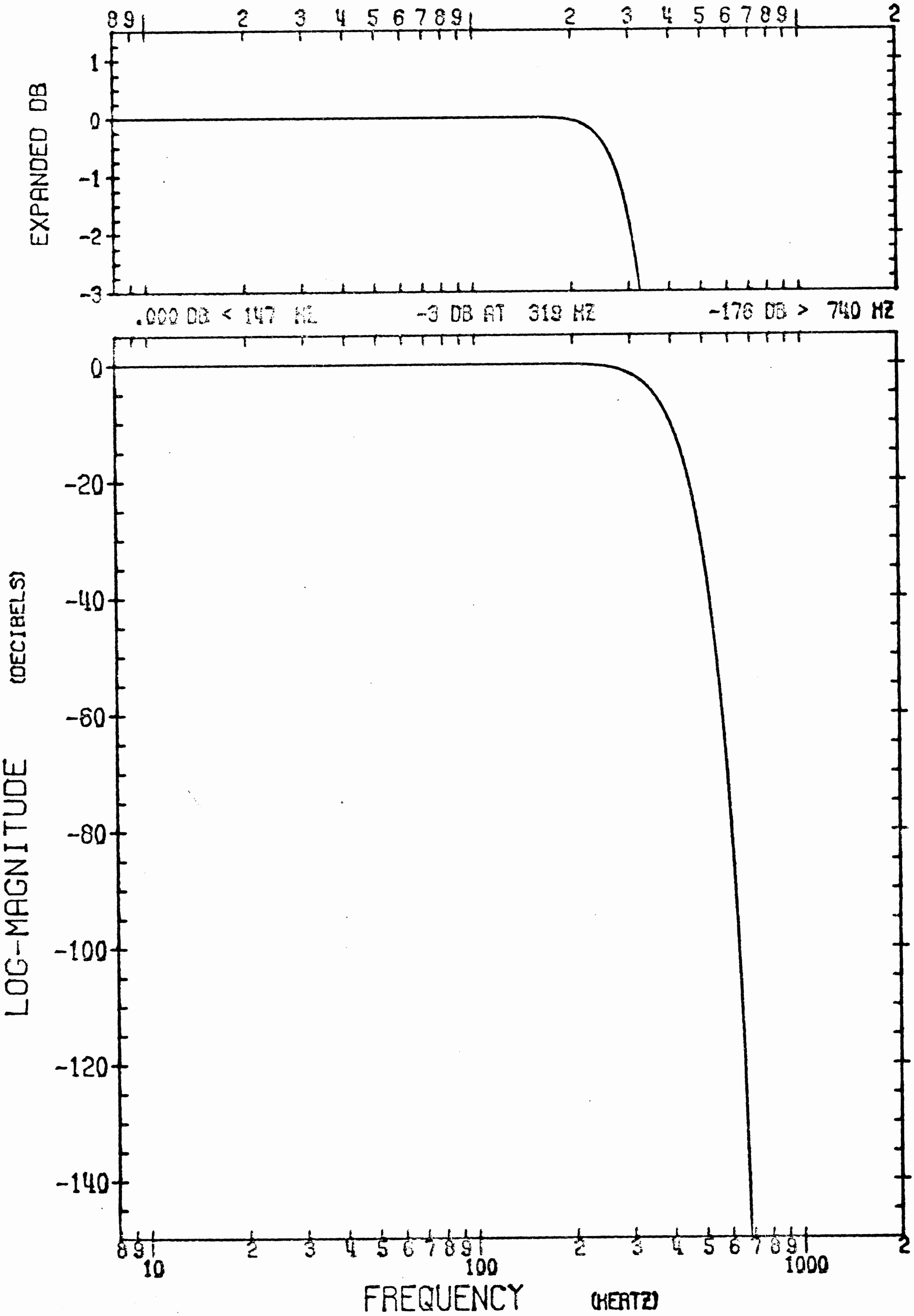
Therefore, the method of applying a given filter should be taken into consideration during its design. Thus, if a low-pass filter must have a gain of -60 dB in the stop-band and ±0.1 dB ripple in the pass-band, and is to be applied twice to a signal, it is sufficient to loosen the stop gain to -30 dB, and to tighten the pass ripple to ±0.05 dB. This should decrease the length of the filter, and possibly shorten the transition band.

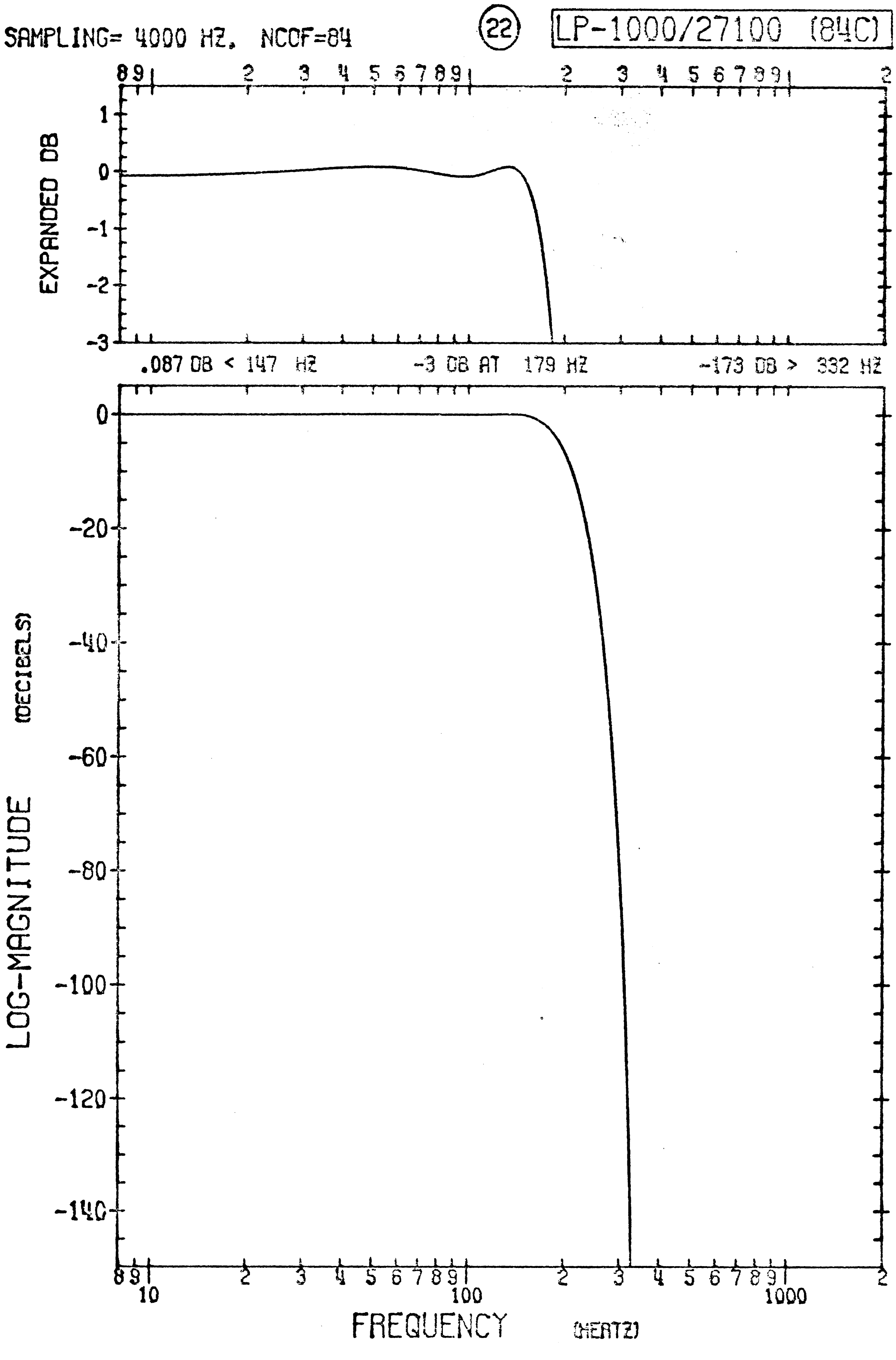


7
SLP-040
SAMPLING= 4000 HZ, NCOF=14
EXPANDED DB
.364 DB < 160 HZ
-3 DB AT 273 HZ
-60 DB > 640 HZ
LOG-MAGNITUDE (DECIBELS)
FREQUENCY (HERTZ)

SAMPLING= 4000 HZ, NCOF=50

(21) LP-1000/27100




SAMPLING= 4000 HZ. NCOF=84
22
LP-1000/27100 (84C)
EXPANDED DB
.087 DB < 147 HZ
-3 DB AT 179 HZ
-173 DB > 332 HZ
LOG-MAGNITUDE (DECIBELS)
0
-20
-40
-60
-80
-100
-120
-140
10
100
1000
FREQUENCY (HERTZ)

E.2.4 Short Bibliography

The following is a list selected from many references used in developing the signal processing package at HSRI:

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