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Experimental Data for Development of Finite Element Models: Head/Thoraco-Abdomen/Pelvis Volume I: HEAD

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16. Abstract

Validation of biomechanical computer models of impact biodynamics cannot be accomplished without descriptive experimental data. The research program, therefore, involved data gathering on the kinematics and damage response of three human cadaver subsystems: the head, the thoraco-abdomen, and the pelvis. 14 unembalmed human cadavers were utilized in 68 dynamic impact tests. The research program entailed 14 head impacts (6 subjects), 41 thoraco-abdominal impacts (11 subjects), and 13 pelvis impacts (10 subjects). In addition, the thoraco-abdominal tests were supplemented with static three-point bending tests conducted on rib specimens from 5 of the dynamically tested cadavers.

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EXPERIMENTAL DATA FOR
DEVELOPMENT OF FINITE ELEMENT MODELS
Contract No. DOT-NHTSA-C-HS-7-01636 UM Acct. No. 015651

OVERVIEW

The research program involved data gathering on the kinematic response of three human cadaver subsystems: 1) the head, 2) the thoraco-abdomen, and 3) the pelvis. Information on injury response as well as the relationship between impact parameters and the resulting injury are presented. Each impact target investigation subsystem is presented as a self-contained chapter in this final report: Chapter 1 presents the head series, Chapter 2 the thoraco-abdomen series, and Chapter 3 presents the pelvis series.

The research program utilized 14 cadavers[1] in 68 dynamic impact tests. For the head subsystem experiments, 6 subjects received a total of 14 impacts; for the thoraco-abdomen, 11 subjects received a total of 41 impacts; and for the pelvis, 10 subjects received a total of 13 impacts. Supplementing some dynamic thoraco-abdominal experiments were static three-point bending tests on rib specimens from 5 of the same dynamically-tested cadavers.

The research program utilized procedures for obtaining kinematic parameters that are still considered the most optimum. Although some procedures were developed prior to these series of experiments, in many instances major improvements in the procedures have been made. In addition, unique methods of analysis using moving frame fields, such as

[1]The protocol for the use of cadavers in this experimental series was approved by the Committee to Review Grants for Clinical Research 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.

the Principal Direction Triad and Frenet-Serret frames, auto- and cross-correlations, and information in the frequency domain, are presented. The program also required the development of a new impact device which increased the magnitude of input force and lengthened the stroke compared to what was previously possible at the University of Michigan Transportation Research Institute's Biomechanics Laboratories.

ACKNOWLEDGEMENTS

The three test series in the Experimental Data for Development of Finite Element Models: Head/Thoraco-Abdomen/Pelvis research program were funded by the United States Department of Transportation, National Highway Traffic Safety Administration, Contract No. DOT-HS-7-01636. The authors wish to acknowledge the technical assistance of Donald F. Huelke, Nabih Alem, John Melvin, Bryan Suggitt, Gail Muscott, Paula Lux, Marvin Dunlap, Don Erb, and Jean Brindamour. The authors also acknowledge the contributions of Jeff Pinsky, Allen C. Bosio, Zheng Lou, Valerie Moses, Wendy Gould, Steven Richter, Peter Schuetz, Shawn Cowper, Tim Jordan, Patrice Muscott, and Reza Salehi. A special thank you goes to Jeff Marcus.

CHAPTER 1

EXPERIMENTAL DATA FOR DEVELOPMENT OF FINITE ELEMENT MODELS - HEAD

Contract No. DOT-NHTSA-C-HS-7-01636   UM Acct. No. 015651

1.0 BACKGROUND

1.1 Head Trauma Incidence

In 1980 U.S. citizens spent four billion dollars to treat acute head injury of over one million individuals [1-10]. Precise figures are not available so it is estimated that 49% of head injuries can be attributed to motor vehicle accidents, 28% to falls and 23% to other causes such as suicide attempts, firearms injury, recreational and occupational accidents [1-10]. Investigation of mechanisms of blunt head impact trauma is invaluable for allocating resources, and for formulating policy to reduce head impact trauma incidence, morbidity and mortality.

1.2 Mechanisms of Injury

Because motor vehicle field accident data do not provide the level of detail necessary to ascertain mechanisms of injury resulting from the interactions of the occupants with the vehicle interior during an accident, biomechanists use trauma experiments to document kinematic parameters so that mechanisms of injury can be better hypothesized, modeled, verified, and simulated.

Determining mechanisms of injury associated with blunt impact to the head can be viewed as determining the forces and the pathways in which those forces act to cause mechanical and physiological disruption. Biomechanists commonly use three approaches in assessing head impact and inertial loading phenomena to determine mechanisms of injury: 1) investigating the material properties and mechanical aspects of the skull-brain-neck system, and then deriving from fundamental laws of physics the biomaterial failure levels or mechanism(s) of injury; 2) performing experiments so that kinematic variables and injury are correlated to deduce or validate injury tolerance levels as well as hypotheses concerning mechanism(s) of injury based on the results; and 3) combining these approaches to modelling mechanism(s) of head injury.

Selecting Kinematic Parameters: A major difficulty in the investigation of head trauma is designing impact experiments which interfere minimally with the biological and physical systems being tested, yet produce results that correspond well with clinically observed trauma and generate useful kinematic data. Some understanding of head injury mechanisms as a result of blunt impact has resulted from relating kinematic parameters to the injury/damage modes produced in experiments with human surrogates. With the possibility of several injury mechanisms and the effects of differences in human surrogates, correlations of this type do not always imply a causal relationship (a mechanism of head injury) for live humans.

The kinematic parameters commonly used for describing head mechanical response during direct blunt impact have been angular and translational accelerations, velocities, displacements of the head as a rigid body, skull bone deformations, and internal pressures in the brain. Many investigators have chosen to investigate a single parameter, such as "resultant head acceleration" for Head Injury Criterion (HIC) calculation, and later use it as an index of severity or tolerance threshold. Because of the complex response of the head to blunt impact, it may be necessary to use several kinematic parameters and relate these to the subject's injury/damage response in order to accurately characterize and predict the response of the living human head to blunt impact.

Injury Response: For biomedical and biomechanical purposes "head injury" is defined as physiologic dysfunction or anatomical alteration of cerebral blood vessels, nerves, brain, skull and scalp. Injury can be classified as "tissue damage" or "concussion".

Tissue Damage - "Linear fractures" may be a complete break through the skull bone, or limited to only one layer. Linear fractures of the cranial vault may extend to the skull base. "Depressed fractures" are inward displacements of bone, with fragments of the skull being displaced into the dura mater and brain.

"Epidural hemotomas" are usually due to a tear of the middle meningeal vessels. When cerebral arteries or veins are lacerated, the resulting "subdural hematoma(s)" produce masses which can compress brain tissue and vessels. A "subarachnoid hematoma" is one located on the pia mater which directly covers the brain. "Petechia" are small hemorrhagic spots on or in the brain tissue. "Intracranial hematomas" are located within the brain. A "contusion" is a laceration of tissue.

Analysis - Measurements obtained from accelerometers, strain gauges, and pressure transducers affixed to a human surrogate subject define the kinematic responses to blunt impact to the head used in experimental analysis. Although there are other human surrogates for modelling the kinematic-injury/damage response of live humans, two are frequently chosen for blunt head impact research. They are the non-human primate and the human cadaver. The geometry and soft tissue distribution of the unembalmed repressurized cadaver is similar to that of a live human. Damages to repressurized cadavers that correlate well with clinically-observed injuries are those that can be documented by gross autopsy. They are tissue damage injuries that include scalp lacerations (linear, flap, stellate), fractures of the cranial vault or base (linear, depressed), lesions which are visible to the naked eye (contusions), and hemorrhage (petechia, subdural-, subarachnoid-, and intracranial hematomas). Because diagnosis of concussion requires the observation of physiologic and behavioral responses, the cadaver model is inappropriate. Instead, a non-human primate or other animal model is used to assess abnormal behavioral responses and neurologic deficits when studying concussion injuries.

Concussion Injury - Trauma to the brain may cause neurologic dysfunctions termed "concussion". These dysfunctions can be transient so that normal neurologic functioning returns and impairment is negligible, or they can be long-term and entail permanent disability. Symptoms can include dizziness, shock, weakness, paralysis, vomiting, rapid pulse, flushed face, headache, unequal pupils, and unconsciousness. "Neurologic deficit" can include sensory loss, lessened sensitivity to touch, visual field defects, fixed or non-reactive pupils, deviation of both eyes to the same side, the inability to use connected phrases when speaking, paralysis affecting one side of the body, and seizures.

"Mild concussion" can be considered a temporary disturbance of neurologic functioning without loss of consciousness. "Cerebral concussion" can be a resumption of normal neurologic functioning after disruption and loss of consciousness of less than 24 hours. Coma can be a deep stupor from which the patient cannot be aroused by external stimuli. These definitions evolved from non-invasive assessment of motor, verbal, and occular behavioral responses. Where diagnostic information has been available from more invasive technological (CAT-scan, PET, NMR, X-Ray) or pathologic (biopsy, autopsy) sources, the brains of some of those suffering concussion have failed to show discernible gross structural injury; the brains of others have shown miscroscopic disruptions of white matter fibers throughout both cerebral hemispheres. Perhaps some diffuse injuries such as extracerebral hematomas may be treatable so that disability is negligible, while others involving extensive microscopic disruption of nerve fibers may prove to be causes of long-term permanent disability. [11-32]

Validating Mechanisms of Injury - There are at least four classes of difficulties which limit understanding the mechanism(s) of injury. These are: 1) complex head geometry and boundary conditions between different head components, as well as dissimilar biomaterial tolerances for different head/brain structures, 2) difficulty of relating injury to a numerical value on an index, 3) human surrogate model limitations, and 4) technical instrumentation and experimental limitations.

1) Head Geometry and Boundaries - The human head is a complex geometric structure. The structural characteristics of the skull contribute to its physical response so that blunt impact to the head is mediated by several protective features. For example, the scalp covering the skull absorbs and redistributes energy resulting from a direct blunt blow to the head. When hit, the bones and sutures in the skull tend to produce a transmission of energy through the skull along complex paths. The different skull thicknesses function like ribs and buttresses enhancing the skull's strength. The domelike shape

of the skull deflects blows. The mobility of the head upon the neck permits energy absorption. Furthermore, the gelatinous brain is bathed in pressurized fluid within interconnecting meningeal membranes. Energy transmission through such a system is complex. Appendix A briefly describes the common gross functional and structural components of the head. [33-36]

Biomaterial Tolerances - In general, the tissues of the head can be viewed as inhomogeneous, anisotropic, viscoelastic, strain rate dependent, and non-linear in response. Biomaterial parameters for head component solids, gels, fluids, and gases include density, hardness, fracture toughness, compressibility, elasticity, viscosity and turgidity [37-110]. Simplifying assumptions are commonly made for biomaterial properties so that an analytical understanding of the mechanism of injury can be assessed by nonbiological material means, that is, in terms of classic mechanics structures such as rigid body materials.

2) Injury Severity Indices - Although much tolerance data comes from materials testing of isolated head biomaterials, injury severity indices which establish "safe" levels for the head may be based on limited experimental test series which have over-simplified the basic dynamic and injury problem. [111-137] In such instances there is a danger of accepting one mechanism of injury, when several may more accurately characterize the dynamic possibilities.

Injury severity indices have been developed for a variety of purposes. The four most common types of indices are: 1) medical injury severity, 2) field accident assessment of tissue damage, 3) laboratory assessment of relationships between kinematic parameters and biomaterial failure levels, and 4) regulative assessment of performance standards of safety equipment.

Medical injury severity scoring systems were designed to provide a standardized format for management of head injury cases to expedite emergency trauma care and to assess the patient's chances for recovery. The aim was to have a system which gave equal ranking to levels of severity for all types of injury. Risk to life evolved into the main medical trauma severity criterion. Perhaps, the most widely used injury severity indices developed by medical personnel pertinent to transportation-related trauma investigation are: 1) The Abbreviated Injury Scale (AIS-80) [111] and 2) The Glascow Coma Scale (GSC) [134].

The AIS-80 is a tissue damage scale developed by the American Medical Association and refined by the American Association of Automotive Medicine. It is used by accident investigators to score tissue damage for a uniform national data base. The data base is useful to engineers, physicians, and legislators for assessing vehicular trauma for their specific needs.

In biomechanics laboratories scientists have formulated kinematic indices related to head injury severity as a by-product of their primary investigation into mechanism(s) of head injury and biomaterial tolerances. Some laboratory indices are the J Tolerance Index (JTI), the Revised Brain Model (RBM), the Effective Displacement Index (EDI), and the Maximum Strain Criterion (MSC) [132].

In regulative settings, laboratory severity indices have been used to define safety test procedures [138-152]. Currently head trauma is assessed by the Head Injury Criterion (HIC) index. This index evolved from the Severity Index (SI) to the Wayne State Tolerance Curve (WSTC) to the HIC. Because indices can become part of protective regulations, it is important to have a clear idea of what any particular severity index is measuring and how well this relates to mechanism of head injury or to clinical outcome, so that preventive measures become indeed pertinent to eliminating or reducing causes of head injury. Because laboratory severity indices often correlate one parameter with one outcome, performance standards are meaningful only in a particular context. One parameter relates to the one outcome in that circumstance and may not accurately represent a parameter level that can be tolerated by live humans in another. Injury severity indices should be validated by correlating them with laboratory observations and medical outcomes. As vehicle interiors and safety devices change, laboratory tests should reflect these new designs. Multiple kinematic parameters need to be correlated with various mechanisms of injury and experimental contexts before head injury tolerance thresholds become truly predictive of head injury and of a patient's prognosis for recovery.

Injury severity indices may inhibit characterization of mechanisms of head injury. By reducing pathologic injury/ damage to a numerical value on an injury severity tolerance scale, valuable descriptive information for understanding mechanisms of head injury is lost. The scales may not include type of injury, location of injury, the number of injuries, the relationship of each injury to the other or of one mechanism of injury to the others.

A weakness of most injury severity scoring schemes is that multiple injuries are scored as one injury. Injuries of varying severity can be misinterpreted as injuries of different types. The result seems to be that such scales may not really characterize injury sufficiently for induction of mechanism(s) of injury. The logic of some injury severity scoring schemes under-characterizes injury. The AIS-80 codes for lesions. Although a similar size lesion of the frontal lobe is not the same as one of the brain stem because the brain is disrupted functionally in different ways by each, the AIS-80 does not reflect this. The Glascow Coma Score is another example: it codes for eye opening, verbal and motor function, but other aspects which may diagnostically be equally meaningful, such as whether the brain stem reflexes are intact or whether the pupils react, are ignored [134-135].

3) Model Constraints - Cadaver subjects have some disadvantages as experimental models. Biological material degrades differentially with time. The changes in the brain material

over time as well as problems with repressurization instrumentation may lead to misinterpretation of head damage response in the cadaver model. [153-160]

Using non-human primates as experimental subjects to determine mechanism(s) of injury entails several disadvantages [161-176]. The use of anesthetics and tranquilizers may severely limit muscular response and its accurate assessment. Difference in outcome may more reflect variability in specimens than a contrast between the test subjects and living humans. Translating and scaling such data is constrained not only by statistical, mathematical and experimental techniques but also by what is still unknown about quantifying differences between and among these test subjects as surrogates for living humans.

Other models such as anthropomorphic test devices ("dummies") and finite element simulations also present empirical problems for validating mechanisms of head damage. The particular dummy may not be repeatable or may be accurate for anterior-to-posterior direction impact but not for lateral or other direction impacts [177-182]. Although finite element models can be very worthwhile for illustrating the mechanical significance of such structures as the foramen magnum, tentorium cerebelli, and falx cerebelli in mechanism of head damage, such models require components which are not true characterizations of biologic reality. Currently because of cost and model limitations, linearity of response and homogeneity of biomaterials must be assumed. Plus, the model may have to be manipulated by pre-selecting biomaterial values which match laboratory observations [183-189].

To maintain an effective research design, it is important to judiciously select the human surrogate which is most appropriate for the aspect of the head trauma problem being investigated and for the type of response data being gathered. The model selected should be one that can best answer the questions being posed in the test design.

4) Technical Constraints - Data collection may be hampered by mechanical conditions in the laboratory setting. Accelerometers may register outcomes that have been mediated by the accelerometers' response to temperature, cross-axis sensitivity, or high/low frequency noise. Instrumenting the skull for attachment of pressure transducers is an invasive technique that requires coring a small hole in the skull. Tracking anatomical movement through space and time relies on the movement of phototargets, which is recorded on film and then digitized. Error can be introduced by both the targeting and digitizing procedures. Accelerometers may not be properly aligned before impact. The response of the test subject is almost invariably determined in part by the instrumentation procedures. The testing apparatus may not be able to produce the type of impact conditions that are seen in the automobile environment.

2.0 HISTORY OF THE LITERATURE

The history of head trauma investigation has been complicated by the number of biologic and dynamic variables involved. Preconceptions about mechanisms of head injury/damage influence how laboratory investigations are designed and interpreted [190-323]. Both legislation and product safety testing reflect the development of contrasting philosophical preconceptions about blunt impact head trauma and mechanism(s) of head injury. Since there are too few experimental series to permit statistical manipulation of the thousands of parameters involved in biomechanics testing, researchers of head trauma must carefully design their experiments and be well informed of the conclusions drawn by other researchers and of the preconceptions and biases entailed in designs in order to be economical as well as successful. Severity indices are an alternative to laboratory investigation of mechanisms of head injury. They can be used to set tolerance limits even when an understanding of the mechanism(s) of head injury is absent. Their usefulness is due to statistical correlation of parameters. Understanding of mechanisms of injury results from laboratory investigation and analysis of parameters.

Proposed Mechanisms of Head Trauma - Within the context of rigid-body mechanics, the head rotates, moving forward, backward and sideways. Mechanisms of head injury can include non-impact mobility mechanisms such as inertial forces [324-333] which produce translational and rotational accelerations [334-351], causing differential movement of head components and injury/damage. During blunt impact both contact force [352-387] and inertial forces can be applied to the head. Impact phenomena are complex sequences of mechanical events. Injury can vary with the magnitudes of the forces, the duration of the impact, and the size of the impacting surface. Impact phenomena can produce deformation [388-402], local injuries/damages, and secondary forces such as stress waves that cause skull oscillations and perhaps injuries/damages remote from the contact point of the blunt impact.

The fit between the analysis of experimental investigation of blunt impact trauma and predicting mechanism(s) of injury for live humans in a similar context is limited by the effectiveness of the selected human surrogate for answering the questions posed by the test, by simplifying assumptions made about complex head geometry and complex head biomaterial properties, and by the selection of kinematic parameters. The scientific literature [1-509] reflects the complexities of the problems inherent in analysis of mechanisms of head injury/damage as well as the evolution of ideas about the geometry of the head and the nature of its biomaterials [37-110,403-407]. Laboratory experiments have investigated stress waves through classic shapes such as spheres [403-407] and through classic materials that were viscous, elastic or viscoelastic [69, 85, 107, 394].

Deformation has been examined in the laboratory as a problem related to biomaterial failure levels [388-402, 408-426]. Injury severity indices have been used to attempt to code injuries/damages into equivalent levels of severity [111, 118-120, 134].

The location of the injury/damage and the location of the center of applied force has produced a body of literature on coup forces, counter coup forces [242-249, 286-288], and on rotational versus translational forces [334-351] are purported to cause certain types of injury/damage or secondary parameters such as <u>change in intracranial pressure</u> [427-433].

In the literature "secondary forces" refer to transmission of energy along complex paths. Structural features such as the sphenoid bone wings, the foramen magnum, or the tentorium cerebelli play significant roles in differential movement of head components and in mechanism(s) of head injury/damage [434]. Elevated intracranial pressure or cavitation bubbles [427-433] and deformation become structural features which must be considered in the analysis of dynamic blunt head impact.

Some literature pertains to the predictability of one parameter for head injury/damage. Resultant angular acceleration is used to calculate the Head Injury Criterion (HIC), an injury severity index which has evolved into a regulatory device [435-440].

EXPERIMENTAL DATA FOR
DEVELOPMENT OF FINITE ELEMENT MODELS- HEAD SERIES

3.0 GOAL OF HEAD SERIES IMPACT TESTING

The goal of this test series was to investigate the relationship between selected kinematic parameters and resultant tissue damage caused by blunt impact to the head of the unembalmed, repressurized human cadaver as a surrogate model for living humans. The kinematic parameters selected were force, velocities, angular and translational accelerations, intracranial pressures, skull bone strain, displacements of brain tissue, displacements of the head as a rigid body, and skull bone deformations. A series of laboratory techniques precisely define the selected kinematic and injury parameters. Laboratory techniques and instrumentation procedures were both refined and created for this test series. Specifically, vascular repressurization techniques were refined and new techniques for cerebrospinal repressurization were created. New techniques which allowed high-speed angiographic radiology were created so that viewing in vitro motion of the brain with respect to the skull as well as differential motion of the brain was possible. Analytical procedures were upgraded during this project for obtaining a transfer function between any two transducer time-histories. Time domain procedures using moving frames, Principal Direction Triad, Frenet-Serret, and auto- and cross-correlation were improved. Frequency domain procedures were also refined (power spectra, mechanical impedance, spectral coherence, specialized transfer functions). Assessment of tissue damage was obtained by gross autopsy observations.

4.0 METHODOLOGY:

4.1 Methods and Procedures of Impact Testing:

4.11 Subjects - Six unembalmed repressurized cadavers were tested. The cadaver subjects were obtained by UMTRI from the University of Michigan Medical School Department of Anatomy.

There were two cadaver test series. In the first series, four cadavers were each subjected to a series of up to three head impacts using the UMTRI linear pendulum impacting device with either a 25 or 56 kg impactor. The remaining two cadavers were subjected to two head impacts each using the UMTRI pendulum impacting device with a 25 kg impactor. The cadavers were instrumented with a nine-accelerometer array on the head to measure three-dimensional motion. Both the cerebrospinal and vascular systems of the cadaver head-brain complex were repressurized. Epidural pressure transducers were used to monitor pressure changes of the skull-brain interface during impact. High-speed photokinemetrics were obtained using normal photographic or cineradiographic techniques. For some cadaver subjects, a radiopaque brain gel was used as a motion descriptor aid.

The execution and coordination of the testing sequence is guided by the use of a detailed protocol which is included in Appendix B [441-496]. The testing sequence is outlined below and additional information about application of specific techniques to analogous biomechanics problems can be found elsewhere [497-509]. Four groups of procedures are associated with the impact testing-data gathering activities. They are:

1) pre-test preparation, 2) instrumentation surgery, 3) trial test and impact testing, and 4) post-test autopsy and injury reporting in DOT format.

4.12 Pre-test Preparation - The arrival of a test subject cannot be predicted more than a half a day in advance. Generally, preparation for a test sequence begins the day a subject is received. The subject requires a day and a half of preparation, which is sufficient time to set up the impact lab and run equipment checks which include a trial test. The areas requiring special preparation are outlined below.

Morgue - Following transfer to UMTRI, cadaver subjects are stored at 4°C in coolers until subsequent use.

Anatomy Lab - Sanitary preparation, anthropometry, and surgical instrumentation of the test subject is done in the Anatomy Lab. All tools, materials, and instrumentation equipment necessary to prepare the subject are constructed or laid out in advance. Included in the setup are surgical instruments, measuring equipment, gauze and toweling, accelerometer mounting hardware, modified French Foley catheters and other pressurization hardware, and clothing for the cadaver subjects.

Radiology Lab - The table and X-Ray head are positioned and a sufficient supply of film is loaded into the X-Ray cassettes. Adequate film is loaded so that the test sequence can be completed without interruption. A subject may be X-rayed here on three occasions: when it is received to check for structural integrity and surgical implants, after instrumentation to check that equipment is positioned properly and pressurization fluid can flow correctly, and when the impact testing is over, orthogonal X-Rays of the head are taken.

Dark Room - Chemicals are mixed for X-Ray developing. Labels for X-Rays are prepared. Courier forms and packaging for the 16 mm high-speed films are readied.

Physiology Lab - 16 mm high-speed films are chemically hypersensitized in an oven at 30-35°C with forming gas for 24 hours in order to obtain better image clarity. The saline-dye pressurization fluid is prepared here. Dental acrylic to be used as an instrumentation mounting medium is mixed here under a hood. In addition, the radiopaque brain gel target is manufactured in the Physiology Lab.

Impact Lab - Test facilities, recording equipment, accelerometers and transducers must be assembled, wired, and trial-tested. In addition, a portable cart containing surgical equipment for wiring the subject with accelerometers and transducers is prepared. Impact padding (styrofoam and ensolite) and support materials for the subject (balsa wood, foam, rope) are assembled near the impact pendulum. The cineradiograph system is readied, the Polaroid and high-speed cameras are tested and loaded with film. All electrical equipment is connected to a power source.

Impact Lab and Instrumentation Room Electronics - The input/output voltage characteristics of all analog tape channels are checked by calibration at predetermined voltage levels. The tape channel calibrations are determined when the test pulses are played back off tape through a computer routine.

All accelerometers and pressure transducers are labeled and wired through a patch panel into the Instrumentation Room. From there, the signals are passed through amplifiers if necessary and connected to their designated channels as input to the analog tape recorders. Amplifiers are adjusted for the proper gain. The accelerometer and pressure transducers must have their excitation voltages set on the amplifiers, while their piezoresistive nature requires balancing to be performed on the amplifiers. Instrumentation Room wiring cannot be completed until the timer box and the devices it operates, such as lights, high-speed cameras and cineradiograph, and ropcutters, are wired and set for the proper control, delay and run times. Final wiring is completed in the Instrumentation Room and the pendulum is prepared for a trial test.

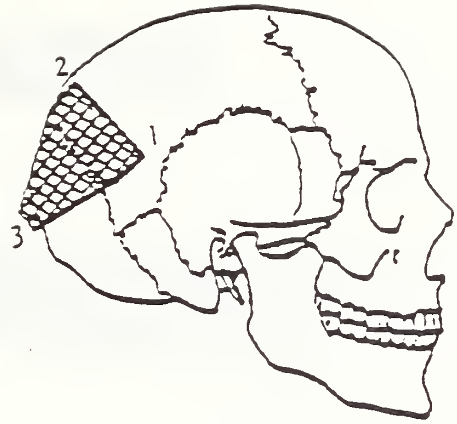
4.13 Surgery - In the Anatomy Lab the test subject is surgically instrumented with the required test hardware. The hardware includes accelerometer mounts, pressure transducer fittings, vascular and cerebrospinal catheters, and a nine-accelerometer head plate.

Nine-Accelerometer Head Plate - The nine-accelerometer plate is installed in the following manner. A two-by-two inch section of scalp is removed from the right occipital-parietal area. Four small screws are then placed in a trapezoidal pattern in the skull within the dimensions of the accelerometer plate mount. Quick setting dental acrylic is molded around the screws to form a securing medium. The plate mount is then placed in the acrylic base. See Figure 1A for the orientation of the plate mount.

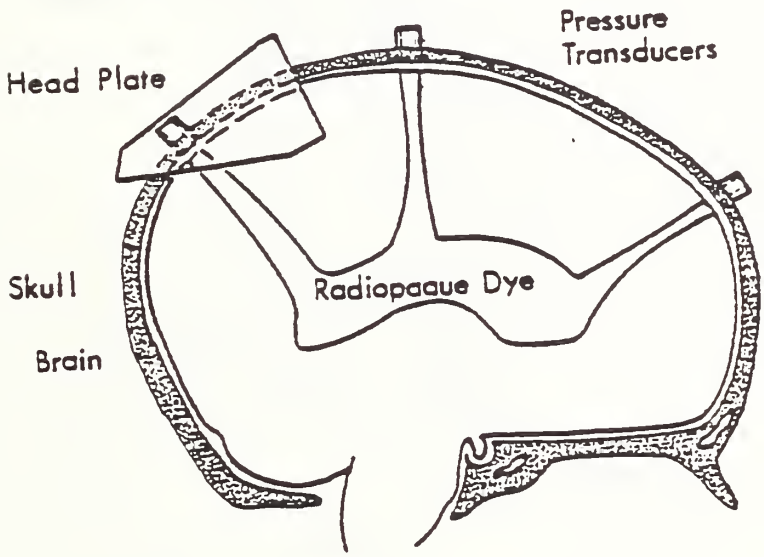
Thoracic Vertebral Mounts - Incisions are made over the T1 and T12 thoracic vertebrae. Supports for the accelerometer mounts are anchored on the lamina for each bilaterally, such that they would flank the spinous process. The accelerometer mount itself is fitted over these supports and screwed directly into the spinous process. Acrylic is applied under and around the mounts to insure structural rigidity (See Figure 2).

Cerebrospinal Fluid Pressure Transducer Fittings - Four 1 cm diameter circles of scalp are removed over the frontal, right and left parietal and occipital bones. A bone coring tool is used to tap and thread four holes in the skull (Figure 3). The brass pressure transducer couplings are twisted into place.

Cerebrospinal Repressurization - The subdural region surrounding the brain and spinal cord is instrumented for repressurization by coring a small hole into the second lumbar vertebra and inserting a Foley catheter under the dura of the spinal cord such that the balloon of the catheter reaches mid-thorax level. To check fluid flow through the ventricles, saline is injected through the Foley catheter until fluid rises to the top of the pressure transducer couplings. The couplings are capped until the radiopaque sodium iodide gel target has been slowly injected through the couplings into the brain cortex and a setup radiograph has been made of the head. The

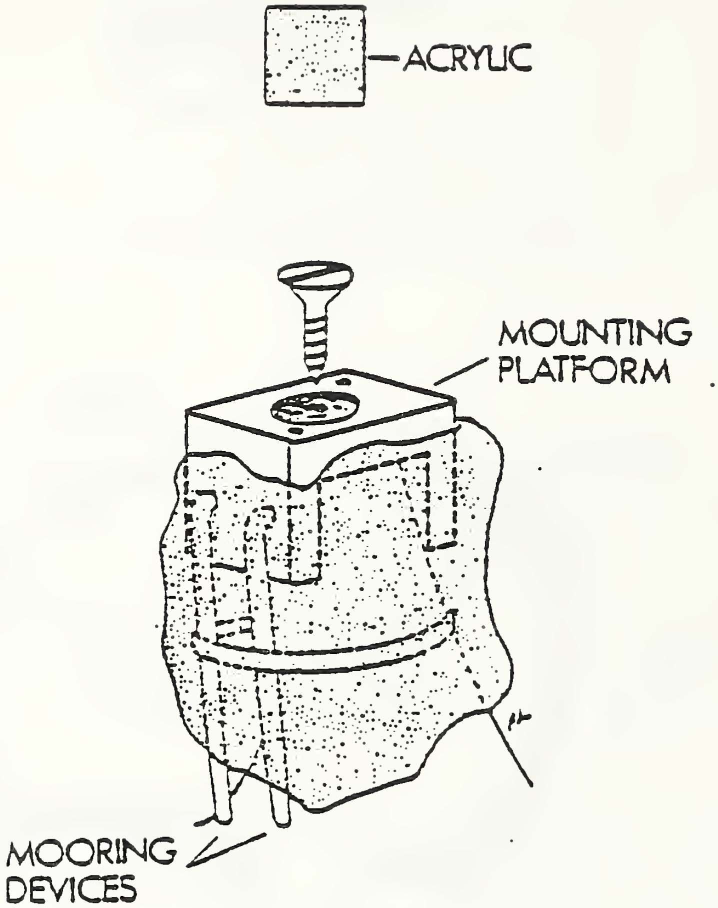


A. Nine-Accelerometer Head Plate Orientation



B. Radiopaque Target Gel in situ

Figure 1



SCHEMATIC REPRESENTATION OF SPINAL MOUNTING PLATFORM

Figure 2

Acrylic for Securing Mounts

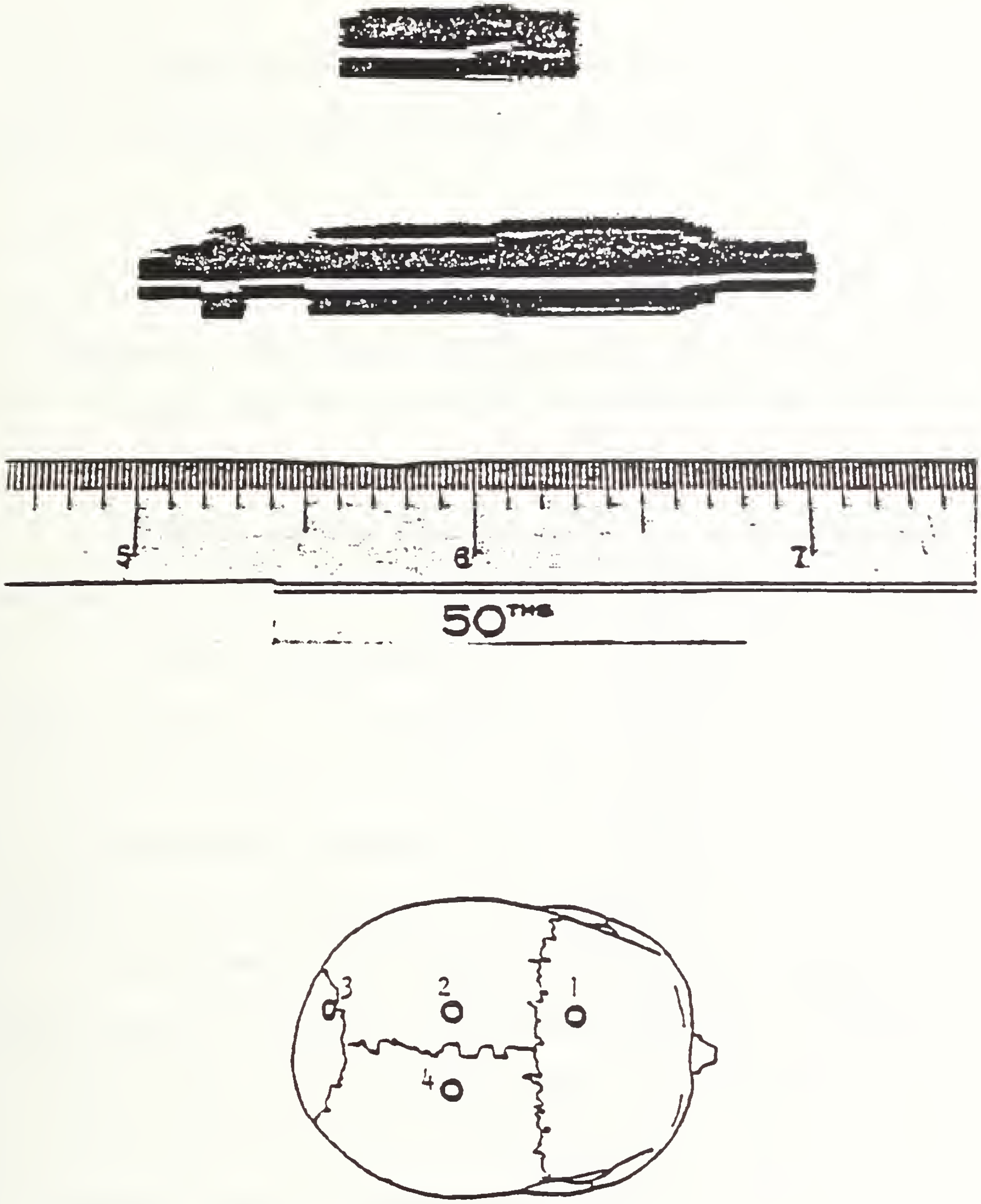


Figure 3

Cerebrospinal Fluid Pressure Transducer Fittings
and Bit

point at which the catheter passes through the lamina of the second lumbar vertebra is sealed with plastic acrylic. (Figure 4).

Vascular Repressurization - To instrument the subject for repressurizing the vascular system of the head, the common carotid artery is located at a point in the neck and an incision is made. (See Figure 5.) A balloon catheter is inserted and positioned such that the balloon is in the internal carotid artery just above the point where the external carotid artery branches. A narrow polyethylene tube is inserted at the same point and passes into the internal carotid artery just past the balloon. A Kulite pressure transducer is then fed through this tube so that vascular pressure may be monitored. Finally, the vertebral arteries are tied off above the clavicle such that fluid pressure in the head may be maintained. Just prior to testing, a solution of India ink and salt is released from a tank into the vascular system of the head. A pressure transducer monitors the flow so that the system is brought to normal physiological pressure immediately prior to impact.

4.14 Trial Test and Impact Testing - To insure that all mechanical and electronic equipment is functioning and wired appropriately for the test design, trial tests of the equipment are performed on the day before the test, allowing sufficient time to locate and correct system defects.

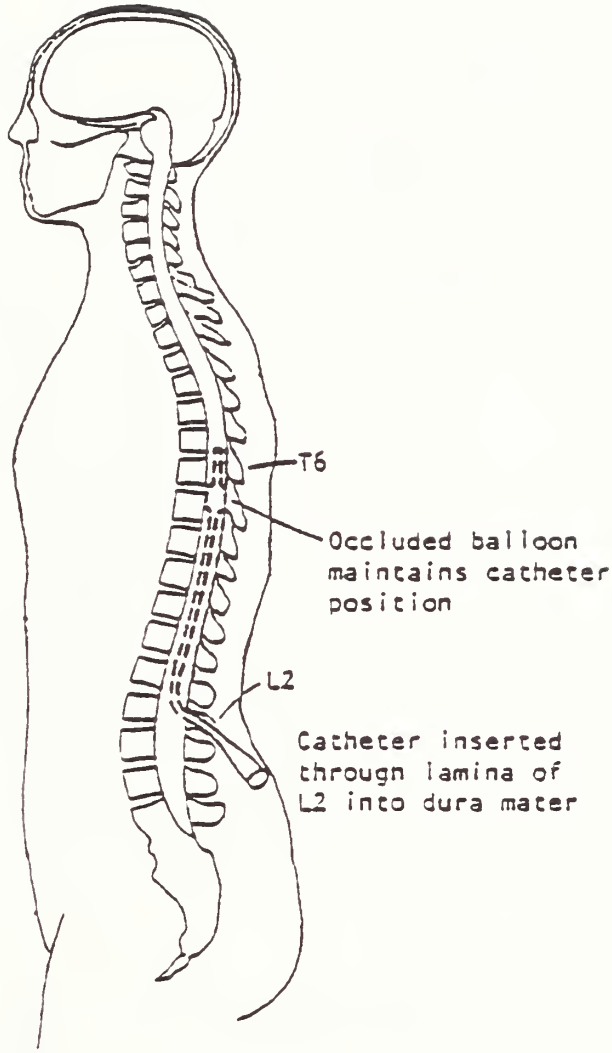


Figure 4

Cerebrospinal Lumbar Catheter

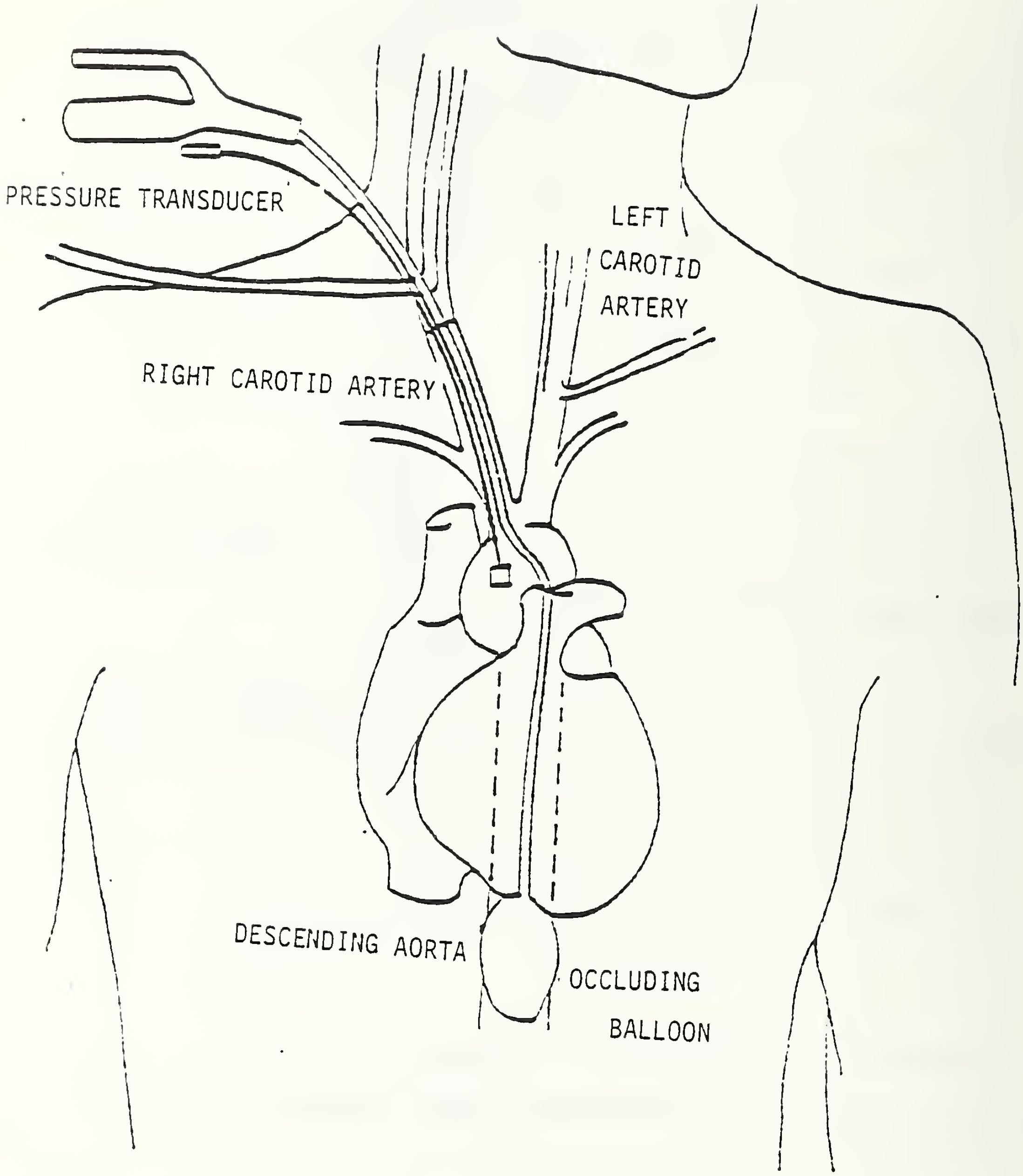


Figure 5

Vascular Repressurization

Trial Test - Accelerometers, amplifiers, umbilical cables, and recorders are tested by suspending a rubber cylinder weighing approximately 20 pounds in front of the pendulum impactor with all of the accelerometers taped to it. A preliminary check of the accelerometers and amplifiers is made to insure proper balancing and noise levels. The pendulum is then manually released via the impactor piston and the rubber cylinder is impacted. The signals from all accelerometers are recorded on the analog tape recorders. All channels are played back immediately on the brush chart for inspection purposes. The pendulum accelerometer is also tested in this procedure. Pressure transducers are tested individually by sending a signal directly to the brush chart recorder. The timer box, cameras, lights, ropecutter, cineradiograph, electroencephalograph, electrocardiograph, and velocity are tested individually. Triaxial clusters, uniax accelerometers and pressure transducers are then labeled for their specific point of attachment to the subject and placed in protective sleeves.

Three classes of operations take place before and during impact that are necessary for the documentation of the impact event: events associated with recording of electromechanical accelerometer and transducer output, events associated with cineradiographic and photometrics documentation, and events associated with the pendulum impactor.

Timing - The impact test event sequence is initiated by an operator-controlled manual switch and is thereafter controlled by signals generated by a specially constructed timer box. The timing requirements of the events associated with these signals are such that the cineradiograph is powered and ready when the high-speed X-ray camera begins to record the test, and that the lights, HyCam and Photosonics 1B cameras are synchronized so that both cameras are running at the correct speed and the test subject is fully illuminated at the time of impact. In addition, the cameras are sequenced to be operational for the minimum amount of time. This economizes the amount of effort associated with photokinemetric documentation (changing film, etc.) and allows for a smoother running test sequence.

The recording equipment must be at operational speed before the pendulum is released. Additional events which must occur just prior to impact are the release of the subject from the restrained position and the activation of the sequencing gate. During the impact event, the output of the piston accelerometer must be fit into a "corridor" or window so that the pre-impact acceleration from rest and the post-impact acceleration from end-of-stroke are not recorded. The pendulum must be released so that impact will occur within the assigned time corridor. A sychronizing contact strobe, which places simultaneous electrical and photographic signals on the analog tape and high-speed film, must occur near the beginning of impact.

Equipment - The basic test equipment includes the timer box control, a signal conditioning unit for the force signal, the accelerometer-transducer patch panels, the impactor, the cineradiograph, the X-ray standby, the high-voltage power supplies, cameras, the photographic lights, and the restraints (hoists, ropecutter). Each piece that plays a significant role in the data acquisition is described below.

Linear Pendulum Impact Device - The UMTRI linear pendulum impact device, using a free-falling pendulum as an energy source, strikes either a 25 or 56 kg impact piston. The piston is guided by a set of Thomson linear ball bushings. Axial loads were calculated from data recorded using a Setra Model 111 accelerometer (Figure 6).

Impact conditions between tests were controlled by varying impact velocity and the type and depth of padding on the impactor surface. Piston velocity was measured by timing the pulses from a magnetic probe which sensed the motion of the targets on the piston.

Ballistic Impact Device - The UMTRI ballistic impact device (Figure 7), consists of an air reservoir, a ground and honed cylinder, and a carefully fitted piston mechanically coupled to a ballistic pendulum. The piston, propelled by compressed air through the cylinder from the air reservoir chamber, serves to accelerate the ballistic pendulum. The mass of the ballistic pendulum can be varied from 10 to 150 kg. The piston is arrested at the end of its travel, allowing the ballistic

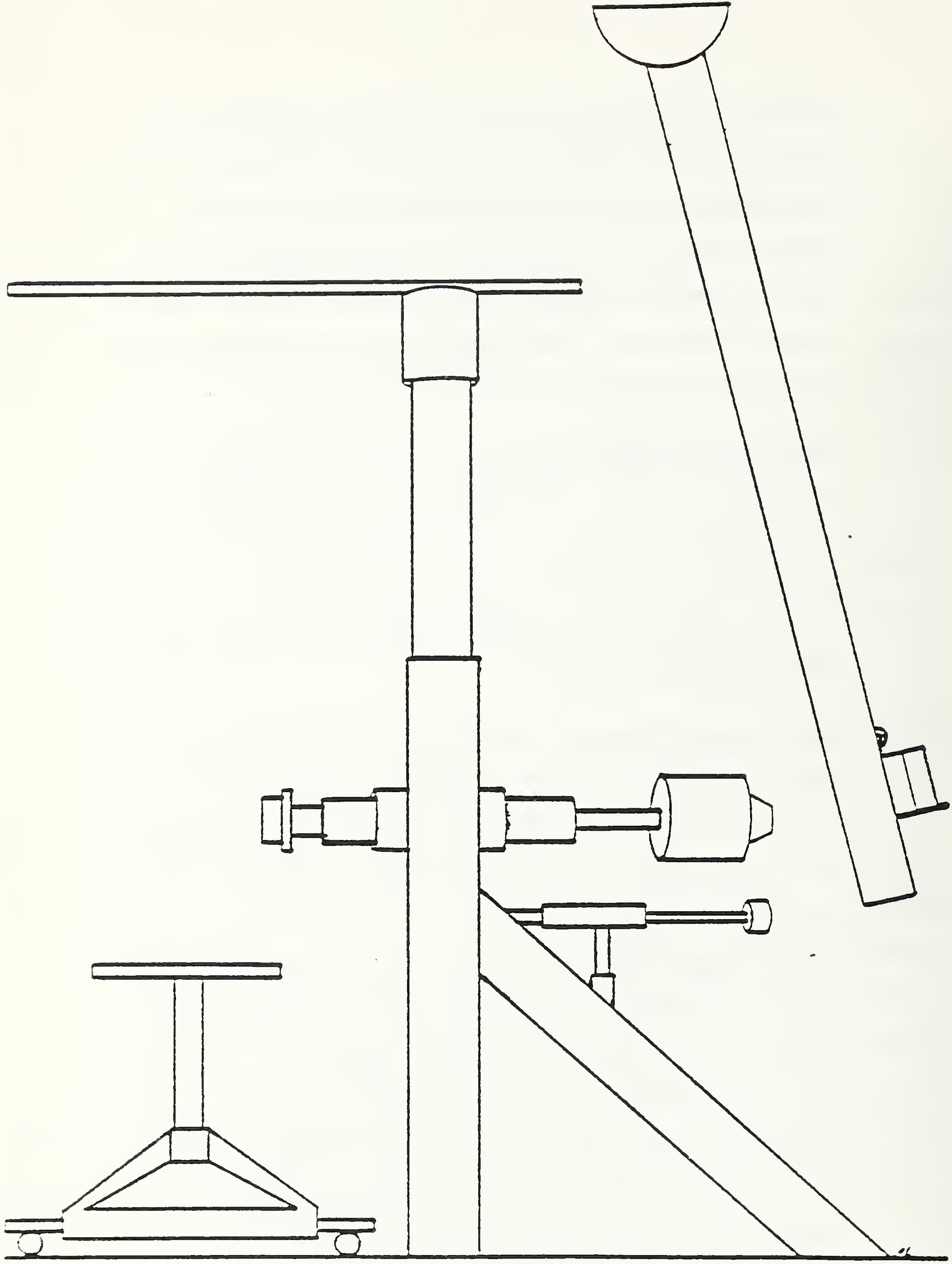


Figure 6

Linear Pendulum Impact Device

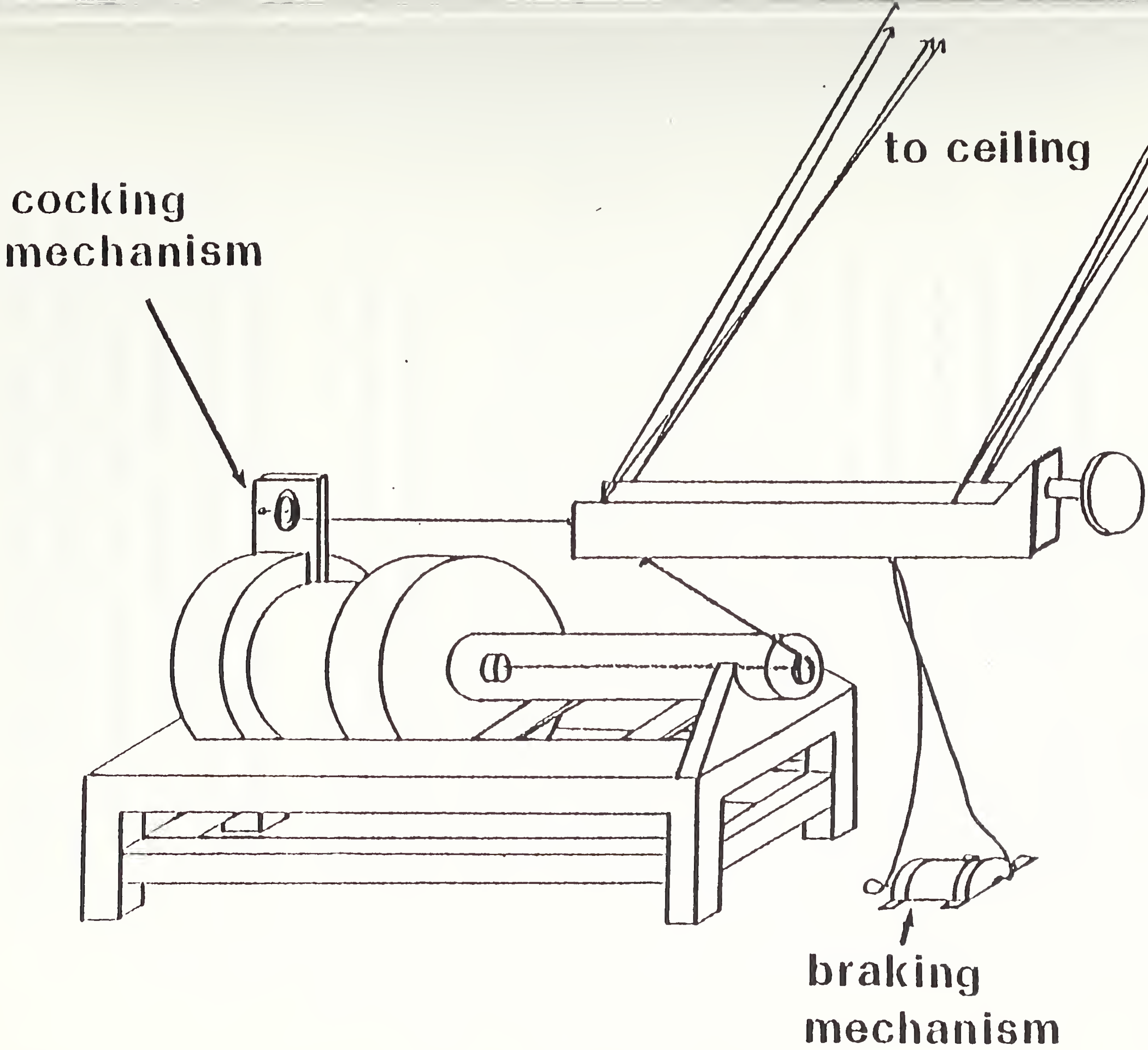


Figure 7

UMTRI Pneumatic Ballistic Impact Device

pendulum to become a free-traveling impactor. The ballistic pendulum is fitted with an inertia-compensated load cell for determination of impact force

Data Handling - All accelerometer and transducer time histories (pendulum force, impact acceleration, epidural pressures, nine head-accelerations) were recorded unfiltered on either a Honeywell 7600 FM Tape Recorder or a Bell and Howell CEC 3300/ FM Tape Recorder. A synchronizing gate was recorded on all tapes. All data was recorded at 30 ips. The analog data on the FM tapes was played back for digitizing through the proper anti-aliasing analog filters. The analog-to-digital process for all data, results in a digital signal sampled at 6400 Hz equivalent sampling rate. It has been reported that skull vibrations above 1300 Hz could cause very local motion in the accelerometer mountings [308]. To reduce this effect, the raw transducer time histories were digitally filtered with a Butterworth filter at 1000 Hz, 6th order.

Epidural Pressure Transducers - Endevco series 8510 piezoresistive pressure transducers were used to measure epidural pressure.

Photokinemetrics System - The motion of the subject was determined from the high-speed (1000 frames per second) film by following the motion of single-point phototargets on the head and on the impactor piston. For selected cadaver frontal head impacts, a Hycam camera operating at 3000 frames per second provided a close-up lateral view of the impact. For these cadaver frontal impacts, the Photosonics provided a overall lateral view at 1000 frames per second.

Analytical photogrammetry is used in these experiments to describe the geometry of anatomical structures and their motion in the laboratory reference frame. The objective space coordinates of points of interest are obtained once the coordinates of well-defined points in an image space and the calibration translation and rotations are specified. The points in an image space are obtained with camera and radiographic equipment and are preserved on film.

Motion of an anatomical structure in space is obtained by measuring the time-history of the position of a photographic target which has a well-defined position and orientation, relative to a predefined anatomical landmark. Defined descriptors of translations and rotations (position, velocity, acceleration) are associated with rigid body motion in object space. Once these descriptors are obtained and digitized, they can then be used to characterize the dynamic response of the subject under study and assist in understanding injury mechanism(s).

In these tests the descriptors chosen are based upon anatomical structures in a two-dimensional image space produced by a point source of X-Rays. The descriptors are two-dimensional and do not take into account rotations and translations which move objects in and out of a plane of gross whole body motion. In addition, changes in the X-Ray cross section of objects can lead to changes in the descriptors which do not have a direct relation to rigid body motion.

Cineradiograph - The UMTRI cineradiograph allows non-invasive viewing of internal anatomical structures in situ. For rigid structures such as bones, the radiopaque targets can be placed on or near anatomical landmarks and motion can be similarly described to that of standard photometric techniques. For soft tissues and some bony structures, descriptors are chosen based upon the shadows of objects associated with anatomical structures.

Radiopaque Target Gel - A neutral density radiopaque gel is used to determine motion of the brain during impact. The gel is injected into the brain through the holes used for insertion of the pressure transducers. The injection technique produces lines of radio-contrast in the brain that show up in high-speed cineradiographic movies. See Figure 1B.

For selected subjects, high-speed cineradiographs were taken. The cineradiographs were taken of the impact events at 1000 or 400 frames per second. The UMTRI high-speed cineradiographic system [497-498] consisted of either a Photosonics 1B or Miliken high-speed 16 mm motion-picture camera which views a 5 cm diameter output phosphor of a high-gain, four-stage, magnetically focused image intensifier tube, gated on and off synchronously with shutter pulses from the motion-picture camera. A lens optically coupled the input photocathode of the image intensifier tube to X-Ray images produced on a fluorescent screen by a smoothed direct-current X-Ray generator. Smoothing of the full-wave rectified X-Ray output was accomplished by placing a pair of high-voltage capacitors in parallel with the X-Ray tube. The viewing field for these experiments was between 20 and 40 cm.

Test Subject Preparation - The unembalmed cadavers were stored at 4°C prior to testing. The cadaver was X-Rayed as part of the structural damage evaluation and anthropomorphic measurements are registered. Next, the cadaver was instrumented, sanitarily dressed and transported to the testing room where the accelerometers and pressure transducers are attached. The subject was positioned. Next, the radiopaque gel target was inserted, and pretest X-Rays and photographs were taken. Pressurization was checked. The subject was then impacted. Each cadaver received either two duplicate head impacts or three triplicate head impacts. Various paddings and padding thicknesses were used.

Initial Test Conditions - Tests 82E001 thru 82E062 used the UMTRI 25 kg linear pendulum impacting device with a 15 cm diameter impacting surface padded with 2.5 cm Ensolite. Tests 83E081 thru 83E103 used the UMTRI 25 kg ballistic impacting device fitted with a 15 cm diameter impacting surface padded with 2.5 cm Ensolite, or a sandwich of 2.5 cm styrofoam, 5 cm Dow Ethafoam plus 2.5 cm Ensolite, or one of 0.5 cm Ensolite, 5 cm seating foam plus 0.5 cm Ensolite. The target area for all of these impacts was the center of the forehead above the orbits (frontal bone). Impact occurred in the anterior to posterior direction. All cadavers were seated and positioned with paper tape so that the subject and the impact target were stable (Figure 8).

4.15 Post-Test Autopsy - After impact testing, the test subject was brought to the Anatomy Lab for autopsy. A gross autopsy was performed. All injuries were recorded in the test protocol on charts and brief descriptions were also written in the protocol. 35 mm still photographs in color and in black and white were taken of all significant tissue damages. These were later coded according to the AIS-80 scheme and reported in DOT format. Occasionally, knowledgeable medical professionals were consulted when more descriptive information might better characterize the observed tissue damages than the AIS-80 coding permits. All of this information was used in the analysis and reconstruction of mechanism(s) of injury and is included in the written reports to the sponsor.

4.2 METHOD OF ANALYSIS - The techniques used to analyze the results are outlined below. Additional information can be found in [311-312, 505-507].

4.21 X-Ray Motion Descriptors - The procedures used for defining X-Ray motion descriptors are explained in [504] and briefly outlined below. Body dynamics no longer offer a good approximation. Several methods have been suggested to produce analytical information describing the soft tissue of the brain. For this project the motion descriptors chosen are based upon

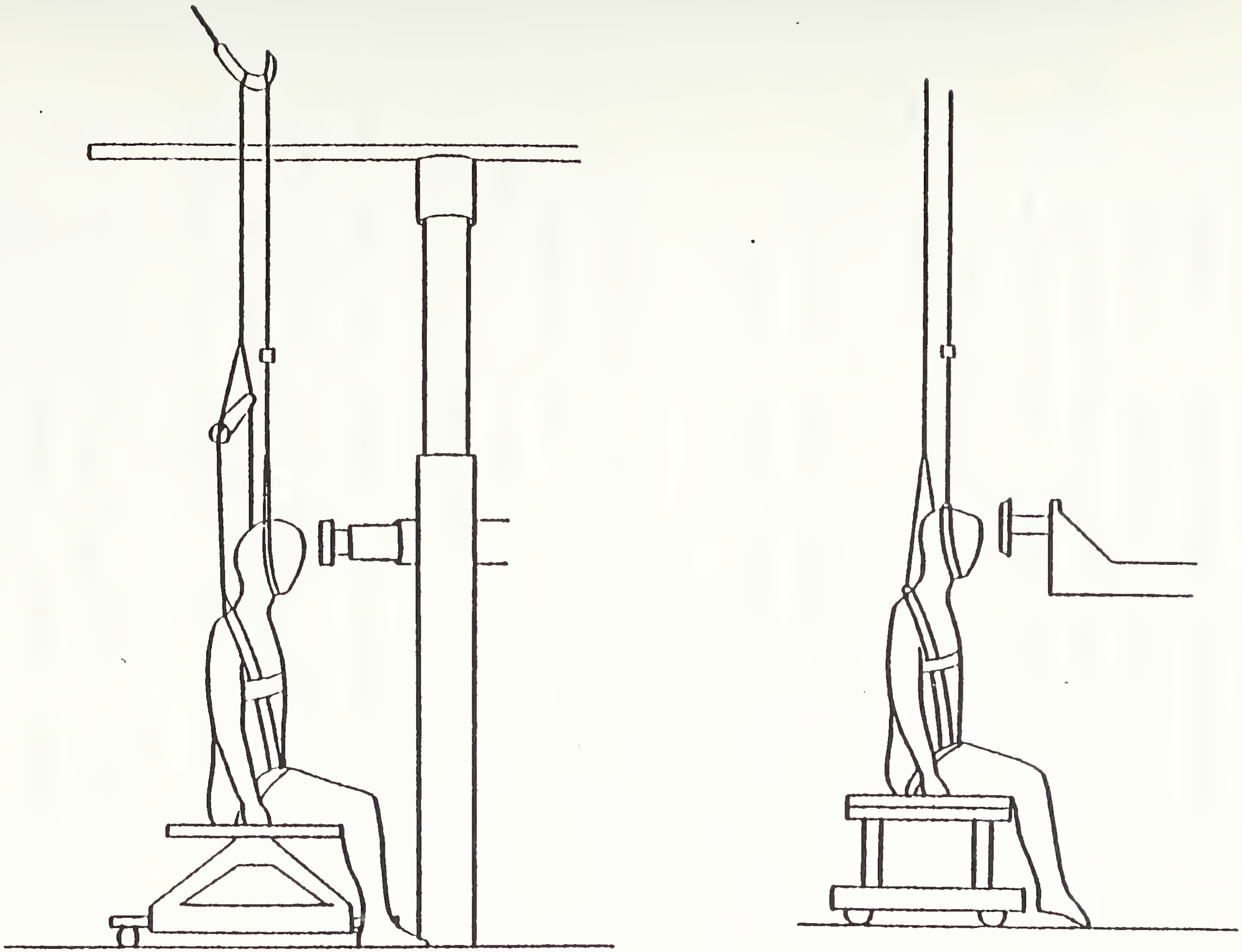


Figure 8

Initial Test Conditions

the shadows of objects in a two-dimensional image space produced by a point source of X-Rays which are associated with the anatomical structures or the radiopaque dye injected into the brain. In the impact tests presented in this report, radiopaque gel was injected into the head producing four curved lines in the brain and outlining the ventricles in some tests. Differential motion between the brain and the skull was obtained by comparing the motion of points on the curve closest to the center of the epidural pressure transducer. General characteristics of the motion of the brain were obtained through the changes in shape of the curved lines and ventricles.

<u>4.22 Frame Fields</u> - As the head moves through space, every point on the head generates a path in space. In head injury research we are interested in the description of the path of the anatomical center and in events which occur as it moves.

It is necessary to determine the instrumentation frame's exact location and orientation in relation to the anatomical frame. A three-dimensional X-Ray technique was developed which requires taking two orthogonal radiographs of the instrumented head. The procedure requires the identification of four anatomical landmarks (two superior edges of the auditory meati and two infraorbital notches) with four distinguishable lead pellets, plus the identification of four lead pellets inlaid in the plate to define the instrumentation frame.

A very effective tool for analyzing the motion of the anatomical center as it moves along a path in space, is the concept of a moving frame [499-500, 508-509]. The path generated as the point travels through space is a function of time and velocity. A vector field is a function which assigns a uniquely defined vector to each point along a path. Thus, any collection of three mutually orthogonal unit vectors defined on a path is a frame field. Therefore, any vector defined on the path (for example, acceleration) may be resolved into three orthogonal components of any well-defined frame field, such as the laboratory or anatomical reference frames. Changes in a frame field with time (for example, angular acceleration of the frame field) are interpreted as vectors defined on the curve and are also resolved into three components.

In biomechanics research frame fields are defined based on anatomical reference frames. Other frame fields such as the Frenet-Serret frame or the Principal Direction Triad [503, 505], which contain information about the motion embedded in the frame field, have also been used to describe motion resulting from impact.

The <u>Frenet-Serret Frame</u> [508-509] consists of three mutually orthogonal vectors T, N and B. At any point in time a unit vector can be constructed that is co-directional with the velocity vector. This normalized velocity vector defines the tangent direction T. A second unit vector N is constructed by forming a unit vector co-directional with the time derivative of the tangent vector T (the derivative of a unit vector is normal to the vector). To complete the orthogonal frame, a third unit vector B (the unit binormal) can be defined as the cross product T x N. This procedure defines a frame at each point along the path of the anatomical center. Within the frame field, the linear acceleration is resolved into two distinct types. The tangent acceleration [Tan(T)] is always the rate of change of speed (absolute velocity) and the normal acceleration [Nor(N)] gives information about the change in direction of the velocity vector. The binormal [Bin(B)] direction contains no acceleration information.

Our method of determining the prinicipal direction of motion and constructing the Principal Direction Triad is to determine the direction of the acceleration vector in the moving frame of the triaxial accelerometer cluster and then assign the transformation necessary to obtain a new moving frame that would have one of its axes in the principal direction. A single point in time at which the acceleration is a maximum was chosen to define the directional cosines for transforming from the triax frame to a new frame in such a way that the resultant acceleration vector (AR) and the "principal" unit vector (A1) were co-directional. This then can be used to construct a new frame rigidly fixed to the triax but differing from the original one by an initial rotation. After completing the necessary transformation, a comparison between the magnitude of the principal direction and the resultant acceleration is performed.

4.23 Transfer Function Analysis - The relationship between an accelerometer/transducer time-history at a given point and the accelerometer/transducer time-history of another given point of a biomechanical system (human surrogate) can be expressed in the frequency domain through the use of a frequency-response transfer function. This input output function is a complex-valued function in the frequency domain and can be expressed by a magnitude and a phase at a given frequency. Transfer functions can be determined from the Fourier transforms of the input-output response time-histories or from the spectral densities of the input and output response signals. In the case of a force and a pressure, such as impact force and epidural pressure, a transformation of the form:

$$(X)(iw) = (F)[F(t)]/(F)[P(t)]$$

can be calculated from the transformed quantities, where w is the given frequency, and F[F(t)] and F[P(t)] are the Fourier transforms of the impact force time-history and the epidural pressure time-history, respectively.

A transformation of simultaneously monitored accelerometer/transducer time-histories can be used to obtain the frequency-response functions of impact force and accelerations of remote points. Once the frequency-response functions are obtained, a transfer function of the form:

$$(Z)(iw) = (w) \quad (F)[F(t)]/(F)[A(t)]$$

can be calculated from the transformed quantities. w is the given frequency and F[F(t)] and F[A(t)] are the Fourier transforms of the impact forces and accelerations of the point of interest at the given frequency.

This particular transfer function is the mechanical transfer impedance which can be defined as the ratio between simple harmonic driving force and corresponding velocity of the point of interest. More information about how mechanical impedance procedures are applied can be found in [501].

<u>4.24 Statistical Measures</u> - To describe some of the fundamental properties of a time-history, such as acceleration or force, three types of statistical measures are used. They are the Auto-correlation Function, the Cross-Correlation Function, and the Coherence Function.

The <u>Auto-correlation Function</u> is the correlation between two points on a time-history, and is a measure of the dependence of the amplitude at time t_1, on the amplitude at time t_2 where t_1 and t_2 are two points on a time-history separated by a given lag $(t_1 - t_2)$. The auto-correlation function is formally defined as the average over the ensemble of the product of two amplitudes:

$$Rx(t_1, t_2) = x_1, x_2, p(x_1, x_2, t_1, t_2) dx_1, dx_2$$

where x_1, x_2 are the amplitudes of the time-history and $p(x_1, x_2, t_1, t_2)$ is the joint probability density. Through the use of a Fourier transform, a discrete time-history of a finite duration is transformed into an auto-correlation function which illustrates the continuous function. For example, the Power Spectral Density Function is a quantity that describes the frequency or spectral properties of a single time-history. It is the Fourier transform of an auto-correlation function and is sometimes called the "Auto Spectral Density" function. Since it is devoid of phase information, only transfer function magnitude can be obtained from the Power Spectral Density Function.

The Cross-Correlation Function is a measure of how predictable, on the average, a time-history at any particular moment in time is from another time-history at any other particular moment in time. The cross-correlation of the time-histories of two signals begins by taking the Fourier transform of both time-histories (Y_1,Y_2). The cross-spectral density describes the joint spectral properties of two time-histories. Phase information is retained in cross-spectral density so that both the magnitude and phase of the transfer function are obtained. The cross-spectral density is the complex-valued function ($Y_1 \bullet Y_2^*$). The cross-correlation is then the Fourier transform of the cross-spectral density.

Cross-correlation between acceleration measurements at two different points of a material body may be determined to study the propagation of differential motion through the material body. Cross-correlation functions are also not restricted to correlation of parameters with the same physical units; for example, the cross-correlation between the applied force and the acceleration response to that force can be determined.

The <u>Coherence Function</u> $cxy^2(w)$, is a measure of the quality of a given transfer function at a given frequency:

$$cxy^2(w) = \frac{|Gxy(w)|^2}{Gxx(w)Gyy(w)}$$

where Gxx(w) and Gyy(w) are the power spectral densities of the two signals, respectively. (Power Spectral Density is a Fourier transform of each signal's auto-correlation.) $|Gxy(w)|^2$ is the Cross-Spectral Density function squared. (Cross-Spectral Density is the Fourier transform of the cross-correlation of the two signals at w, the given frequency.) In general, $0 \le cxy^2(w) \le 1$. Values of $cxy^2(w)$ near 1 indicate that the two signals can be considered causally connected at that frequency. Values significantly below 1 at a given frequency indicate that the transfer function at that frequency cannot accurately be determined. In the case of an input-output relationship, values of $cxy^2(w)$ less than 1 indicate that the output is not attributable to the input and is perhaps due to extraneous noise. The coherence function in the frequency domain is analogous to the correlation coefficient in the time domain. For more information on this measure see [501].

<u>4.25 Pressure Time Duration Determination</u> - Two different types of pressure-time histories were observed, unimodal and bimodal. The unimodal waveform was characterized by one maximum and the bimodal waveform by two local maxima. In order to define the

pressure duration, a standard procedure was adopted which determined the beginning and end of a pulse. This procedure began by determining the peak, or the first peak in the case of a bimodal waveform. Next, the left half of the pulse, defined from the point where the pulse started to rise until the time of peak, was least-squares fitted with a straight line. This rise line intersected the time axis at a point which was taken as the formal beginning of the pulse. A similar procedure was followed for the right half of this pulse, i.e., a least-squares straight line was fitted to the fall section of the pulse, which was defined from the peak to the point where the pulse minimum occurred. The point where this line intersected the time axis was the formal end of the pulse in the unimodal case, and the formal end of the first peak in the bimodal case. The pressure duration for a unimodal waveform was defined by these points. For a bimodal waveform, these two points were used to determine the first pressure duration. Another least-squares straight line was fitted to the fall section of the second pulse. The point at which this line intersected the time axis was the formal end of the waveform, and the total pressure duration was then defined from this point and the beginning point.

4.26 Force Time-History Determination - In general the force-time histories were unimodal with a single maximum, smoothly rising, peaking and then falling. Various padding configurations on the striker surface effected different force time-history durations. Force duration was determined using the same techniques for determining pressure duration, that is similar boundary defining and least-squares straight-line fitting techniques were employed.

4.27 Impact Response Definition - With the use of the UMTRI nine-accelerometer array it is possible to record three-dimensional six-degrees-of-freedom motion of the area of the the skull in which the accelerometers are located. Therefore, head impact response can be defined as a continuum of "events" characterized by the path traced by the motion of the "estimated anatomical center," by all the vectors defined on that path, and by changes of the associated frame fields. Physically this implies that head impact response is interpreted as the response of a material body (the nine-accelerometer array and area of the skull local to it) in contact with other material bodies. The curve and the vectors generated as the "estimated anatomical center" moves in time are, thus, a result of the interactions of the skull-mount area with other material bodies.

Examples of events which are used to characterize head impact are: the initiation of head impact response (denoted by Q_1 on the tangential acceleration time histories in the appendix), the positive maximum of the tangential acceleration time history (denoted by Q_2 in the accompanying data), and the negative maximum of the tangential acceleration time-history (denoted by Q_3 in the accompanying data). In research reported earlier in which similar Q_1, Q_2 and Q_3 events were defined

[302], the tangential acceleration rose smoothly to a single maximum and fell smoothly until crossing zero. In some of the tests being reported here, the time interval near Q_2 contained several local maxima, therefore direct comparison is complex. Nevertheless, these defined events can be used to compare different types of impacts for the same human surrogate and to compare the response of one human surrogate to another.

5.0 RESULTS

Table 1 lists the initial test conditions. Table 2 summarizes the impacts. Table 3 characterizes impact pressures. Table 4 reports the tissue damages. Selected time histories in Appendix C are examples of important kinematic factors associated with the research performed in this test series. The variables these examples illustrate are tangential and normal acceleration, resultant acceleration, rate of change of the tangential vector (T-rate) and rate of change of the binormal vector (B-rate). In addition, impact force, resultant angular acceleration and velocity, linear velocity, and pressures are shown.

The effect of different filtering levels is illustrated in Appendix C by Test 82E041 which is presented at no-filtering, 100 hz, 200 hz, 400 hz, 800 hz, and 1600 hz levels.

Table 1. Initial Test Conditions

Test No.	Subject Condition	Impact Surface Padding Thickness+	Velocity m/s
82E001++	repressurized	2.5 cm Ensolite	5
82E021++	repressurized	2.5 cm Ensolite	5.2
82E022++	repressurized	2.5 cm Ensolite	5.7
82E041++	repressurized	2.5 cm Ensolite	5.5
82E042++	repressurized	2.5 cm Ensolite	5.5
82E061++	repressurized	2.5 cm Ensolite	5.5
82E062++	repressurized	2.5 cm Ensolite	5.5
83E081+++	repressurized	2.5 cm Ensolite	3.8
83E082+++	repressurized	2.5 cm Ensolite	3.8
83E101+++	repressurized		4.5
83E102+++	repressurized	2.5 cm Ensolite 5.0 cm Dow Ethafoam 2.5 cm Ensolite	4.5
83E103+++	repressurized		4.5

++25 kg linear pendulum
+++25 kg ballistic pendulum

Table 2. Impact Test Summary

Test No,	Linear Acceleration Tangent m/s/s	Resultant Acceleration m/s/s	Resultant Angular Acceleration r/s/s	Resultant Angular Velocity r/s	Linear Velocity m/s	Force N	Force Duration ms
82E001	3600	4500	42000	52	5	9100	10
82E021	1400	1440	7500	20	5.2	8400	11
82E022	1900	1900	7250	28	7.0	9600	10
82E041	1800	1800	7000	19	6.4	9600	12
82E042	1600	1800	8000	20	7.5	10200	12
82E061	1600	1700	6000	25	6.5	9000	10
82E062	1500	1600	7500	30	6.5	9600	12
83E081	1350	1350	7500	22	3.8	9600	12
83E082	1250	1000	7000	24	3.5	4100	8
83E101	-	-	-	-		-	-
83E102						1800	64
83E103							

Table 3. Test Pressure Summary

Test No.	Location	Type	Maximum Kpa	Time at Maximum ms	Duration ms
82E001	Epidural 1	Unimodal	75	5	10
	Epidural 2	Bimodal	11,3	5/25	10/120+
	Epidural 3	Unimodal	-36	5	15
	Epidural 4	Unimodal	11	5	5
82E021	Epidural 1	Unimodal	161	5	12
	Epidural 2	Bimodal	48,7	5/40	5/80
	Epidural 3	Bimodal	-61,8	5/45	10/80
	Epidural 4	Bimodal	34,6	5/25	5/70
82E022	Epidural 1	Unimodal	180	5	10
	Epidural 2	Bimodal	47,6	5/35	10/80
	Epidural 3	Bimodal	-43,6	5/50	15/100
	Epidural 4	Bimodal	12,51	5/13	5/5
82E041	Epidural 1	Bimodal	22,2	5/40	15/20
	Epidural 2	Bimodal	-20,11	5/45	10/15
	Epidural 3	Bimodal	-55,28.	5/50	10/40
	Epidural 4	Bimodal	39,31	5/50	10/70
82E042	Epidural 1	Unimodal	58	5	140+
	Epidural 2	Bimodal	-20.9	5/45	5/20
	Epidural 3	Bimodal	-53,13	5/45	10/40
	Epidural 4	Bimodal	/38,42	5/60	5/25
*82E061	Epidural 1	Unimodal	97	5	8
	Epidural 2	Unimodal	24	5	5
	Epidural 3	Unimodal	-31	5	8
	Epidural 4	Bimodal	15/40,7	5	10/150
**82E062	Epidural 1	Unimodal	55	5	12
	Epidural 2	Bimodal	27,12	5/40	10/35
	Epidural 3	Bimodal	31,14	5/42	10/40
	Epidural 4	Bimodal	37,12	5/45	10/40
83E081	Epidural 1	Unimodal	52	5	150+
	Epidural 2	Bimodal	20,14	5/20	10/135+
	Epidural 3	Bimodal	-18,14	5/20	7/125+
	Epidural 4	Unimodal	25	5	75
83E082	Epidural 1	Unimodal	46	5	15
	Epidural 2	Bimodal	10,5	5/20	10/125+
	Epidural 3	Bimodal	-13,3	5/50	10/100+
	Epidural 4	Bimodal	7,4	5/25	5/50

Table 3. Test Pressure Summary (continued)

Test No.	Location	Type	Maximum Kpa	Time at Maximum ms	Duration ms
83E101	Epidural 1	Unimodal	1		
	Epidural 2	Unimodal	1		
	Epidural 3				
	Epidural 4	Unimodal	17		
83E102	Epidural 1	Unimodal	-6	5	
	Epidural 2	Unimodal	-1	5	
	Epidural 3	Unimodal	5	5	
	Epidural 4	Unimodal	2	5	
83E103	Epidural 1	Unimodal	18		
	Epidural 2	Bimodal	18		
	Epidural 3	Unimodal	7		
	Epidural 4	Bimodal	4		

*Epidural 1 = Frontal Bone
Epidural 2 = Left Parietal Bone
Epidural 3 = Occipital Bone
Epidural 4 = Right Parietal Bone

**Epidural 3 = Right Parietal Bone
Epidural 4 = Occipital Bone

Table 4. Damages

Test No.	Gross Skull	Gross Brain	Gross Other
82E001	No abnormality. Parietal fracture. Basilar fracture.	No abnormality. Sub-arachnoid hematoma frontal lobes (cerebrum) and on base of occipital lobe (cerebrum).	No abnormality or injury.
82E021 82E022	No abnormality or injury.	No abnormality. Sub-arachnoid hematoma right frontal lobe (cerebrum), hemorrhage central area left frontal lobe (cerebrum).	No abnormality or injury.
82E041	No abnormality or injury.	No abnormality. Sub-arachnoid hematoma frontal lobes (cerebrum) and subarachnoid.	No abnormality or injury.
82E061 82E062	No abnormality or injury.	No abnormality or injury.	No abnormality or injury.
83E081 83E082	No abnormality or injury.	No abnormality or injury.	No abnormality or injury.
83E101 83E102 83E103	No abnormality or injury.	No abnormality or injury. [Mechanical abnormality of incomplete repressurzation].	No abnormality or injury.

6.0 DISCUSSION

Since the head impact tests entail different initial conditions, impact directions, and locations for the recording instruments, frame-independent variables and Frenet-Serret vectors were used for examination and analysis. Frame-independent variables include resultant angular and linear velocities and accelerations. Vectors expressed in the Frenet-Serret frame field include tangential acceleration, normal acceleration, T-rate and B-rate. The features of the data discussed briefly in this section represent trends that may be important factors in head impact response. In particular, the potential effect of skull deformation on head angular acceleration as well as on impact and injury response appears significant.

6.1 Force Time-Histories - Force time-histories of the head impact tests were divided into two types which correlate well with fracture and non-fracture tests. In non-fracture tests, the force rises smoothly to a maximum and drops smoothly to zero. In fracture tests, although the force rises smoothly to a maximum, the drop to zero has a greater number of inflections or local maxima and is of longer duration. Test 82E001 is an example of a fracture test.

Non-fracture head impacts can be broken into two groups consisting of long- and short-duration impacts. Short-duration impacts are those which last less than 15 ms; long-duration impacts are defined as lasting 15 ms or longer. In some cases, such as Test 83E102, durations as long as 60 ms were recorded. Test 82E041 illustrates a short-duration impact and Test 83E102 a long-duration impact.

6.2 Tangential Acceleration Time-Histories - The tangential acceleration time-histories separate into two groups, correlating well with the presence or absence of subarachnoid hemorrhage. For those tests in which no subarachnoid hemorrhage was observed, the tangential acceleration had a single local maximum in the area of maximum acceleration. However, for those tests in which subarachnoid hemorrhage was observed, there were several local maxima in the area of maximum acceleration.

<u>6.3 Comparison of Impacts: Cadaver Variability</u> - To examine variability within the cadaver subjects, some subjects received two similar impacts (Tests 82E001 through 83E082). Figure 9 is an example of cross- and auto-correlations for Tests 82E021 x 82E022 and 82E061 x 82E062 and 82E021 x 82E061. The figure represents the general trend observed in relating the force time-histories of similar tests with different subjects to similar tests with the same subject. In general, it appears that force time-histories as well as acceleration time-histories vary more between subjects than between tests on the same subject. An analogous comparison for epidural pressures showed equivalent variance between different subjects undergoing similar impacts as between the same subject having similar impacts. This implies that experimental techniques associated with repressurization or with the effects of the postmortem state may produce as much variance in the pressure time-history response as do variations due to the population of test subjects.

<u>6.4 Impact Response</u> - The motion of a rigid body in space is the result of generalized forces: the total force and the total torque about a suitable axis. The dynamic problem of the motion of the area of the skull local to the nine-accelerometer array can be interpreted in the same way. However, due to the complex interactions of the area of

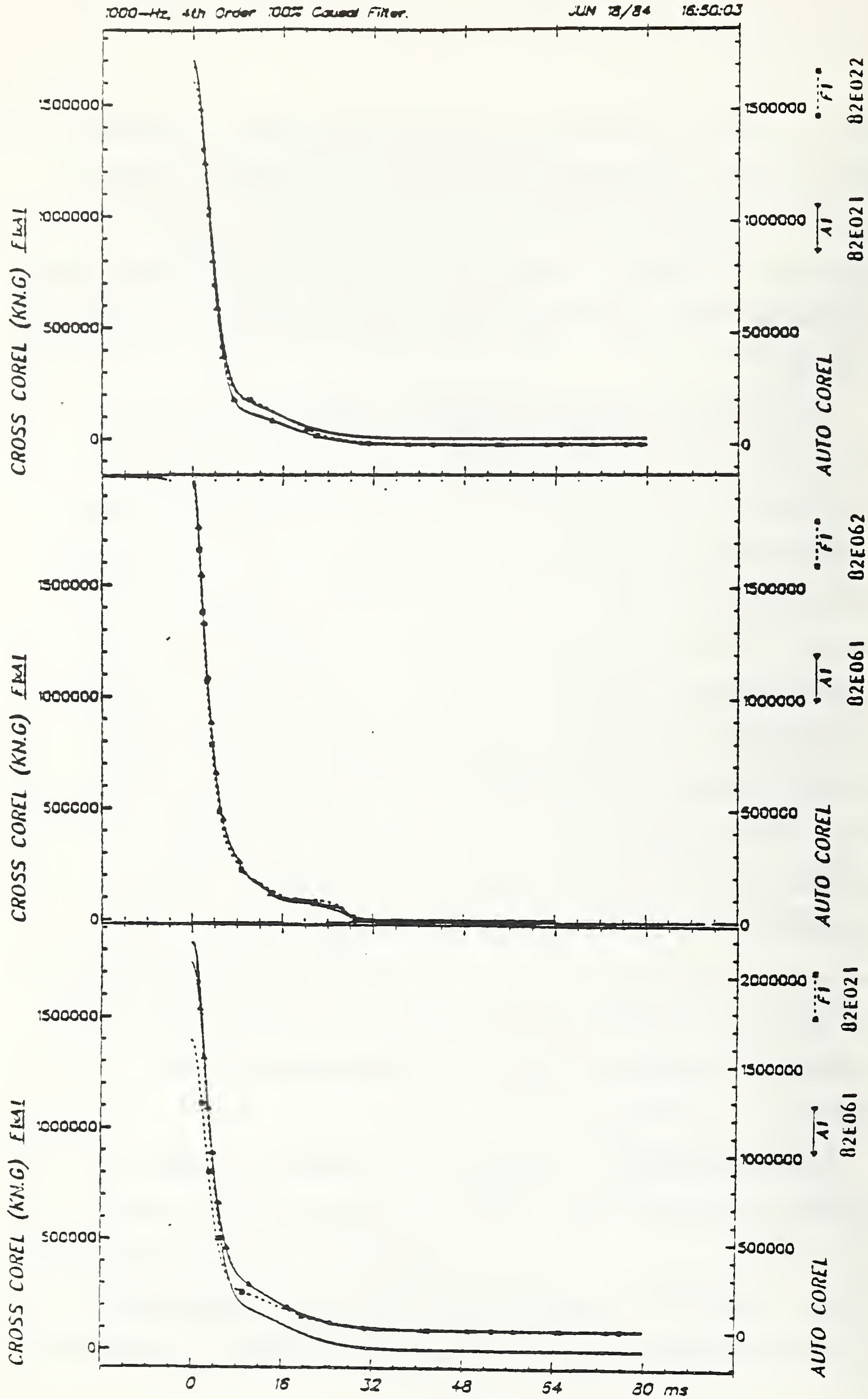


Figure 9

Cross- and Auto-Correlations

the skull local to the nine-accelerometer array with other material bodies, (for example, the muscle soft tissues of the neck, the rest of the skull, the brain, or the impactor), serious problems can arise in determining which of the bodies is producing these generalized forces.

When the head receives an impact, several events occur: 1) stress waves are propagated from the impact site, 2) the skull starts to deform, and 3) the skull begins to move due to the impact, transmitting impact energy to the brain via the dura mater. Eventually, the waves are dissipated, the deformation of the skull recovers partially or fully upon removal of the impact loads, and the acceleration of the skull occurs primarily due to forces generated through the brain and neck. If differential skull motion is severe, essentially due to either sufficient energy in the high frequency components of the force time-history or a sufficient peak force, the stresses at some point in the skull may exceed the failure strength of the bone, thereby producing fracture. The loads producing this type of impact are generally of shorter duration or contain a rise time sufficient to generate the high frequency components necessary to fracture the skull. The motion of the entire skull as a rigid body, as estimated by the nine-accelerometer array, depends on the degree of skull deformation as well as on the degree of precision being used in the investigation. If the skull deformations are small during and after impact, and the accelerometers are far enough from the impact contact point, then valid rigid body motion can be assumed. However, if skull deformations are significant, then three-dimensional motion of the nine-accelerometer array and of the skull local to its instrumentation mount can only be used to estimate the motion of the rest of the skull through the use of an "estimated anatomical center." Interpretation of the results from the nine-accelerometer array must, therefore, take into account the non-rigid body motion taking place during "significant skull deformation" impacts. Using translations obtained from X-rays, three-dimensional approximate motion of an "estimated anatomical center" can be determined.

6.5 Effects of Skull Deformation on Linear and Angular Acceleration

Inspection of the three-dimensional motion of the skull local to the accelerometers, epidural pressure transducer response, and contact forces showed that skull deformation may have important implications for injury produced in blunt head impact.

For tests with force time-histories having unimodal peaks of the anatomical center, "the time interval between the events Q_1-Q_2 is probably primarily a result of the interaction of the impactor with the skull. During the Q_1-Q_2 interval, the "estimated anatomical center" does not move more than 1 cm and the motion is to some extent three-dimensional. This is indicated by the rate of change of the tangent vector (T-rate) and binormal vector (B-rate). A positive T-rate implies a curvature of the path or two-dimensional motion; significant T- and B-rate imply a torsion of the path or three-dimensional motion. However, the angular acceleration is principally in the binormal direction. The normal acceleration of the point on the skull of closest approach to the impactor was found to be less than that of the "estimated anatomical center." Reduced normal acceleration implies a "straighter" path for that point. These measurements of angular and normal acceleration imply that the skull may be rotating about the point of closest approach to the impactor centerline.

For the tests with time-histories displaying multimodal peaks of the tangential acceleration of the "estimated anatomical center" in the vicinity of the Q_2 event, the time interval between the events Q_1-Q_2 is probably a result of the interaction between impactor and skull. However, in these tests skull deformations seem to have significant effect on the angular, tangential, and normal acceleration responses. Comparison of this multimodal impact response (Test 82E041 for example) to the unimodal tangential acceleration response (Test 82E061 for example), shows that the following variables are greater during the Q_1-Q_2 interval of the multimodal impact: angular acceleration, normal acceleration, T-rate and B-rate. This implies that for the multimodal type of impact, the path of the "estimated anatomical center" is moving in a three-dimensional manner to a greater extent than the same path for the unimodal pattern impacts. This increased level of three-dimensional motion correlates well with the angular acceleration.

Comparison of the ratios of peak angular acceleration and velocity during the Q_1-Q_2 interval to the respective peak angular acceleration and velocity during the Q_2-Q_3 interval indicates that for a given multimodal impact, there is greater angular acceleration response during the Q_1-Q_2 interval. In addition, the local maxima of the angular velocities in the multimodal impact as well as the rapid rotation of the binormal and normal vectors of between pi/2 and pi radians indicates that the path of the "estimated anatomical center" has passed an inflection point near the Q_2 event. This is most evident when the skull fractured. In a skull fracture test, the head is loaded very rapidly (e.g., Test 82E001, while the force drops, the tangential acceleration drops below zero). This is accompanied by a short-lived rotation of the skull which produces a local maximum in the angular velocity. Subsequent to fracture, the skull is in more complete contact with the impactor. The tangential acceleration increases, the angular velocity decreases, and the angular acceleration reverses direction.

The head is generally modeled as a rigid body when interpreting angular acceleration from nine-accelerometers. However, the complex nature of the skull geometry [262, 494-495] causes asymmetric loading during blunt impact, which leads to an interpretation of an angular acceleration by the nine-accelerometer array that is not directly related to rigid body motion. Therefore, in addition to local skull bending in the area of the nine-accelerometer array, a second mechanism of skull deformation which causes the accelerometers to interpret angular acceleration can be hypothesized.

A schematic display of this type of response is presented in Figure 10 to illustrate the effect of skull deformation on angular acceleration (a rotation is produced). This figure demonstrates the type of motion that might occur and is not necessarily representative of motion actually observed. Also, motion of the skull is not necessarily in the anterior-posterior, inferior-superior plane. Since angular displacement is small, movements are best detected through evaluation of angular acceleration.

Angular acceleration is an acceleration gradient over displacement at a given instant in time, so the results of the linear acceleration are influenced by the angular acceleration. Thus, the differences in the vicinity of the Q_2 event between the multimodal aspect and the unimodal aspect of the tangential acceleration of the "estimated

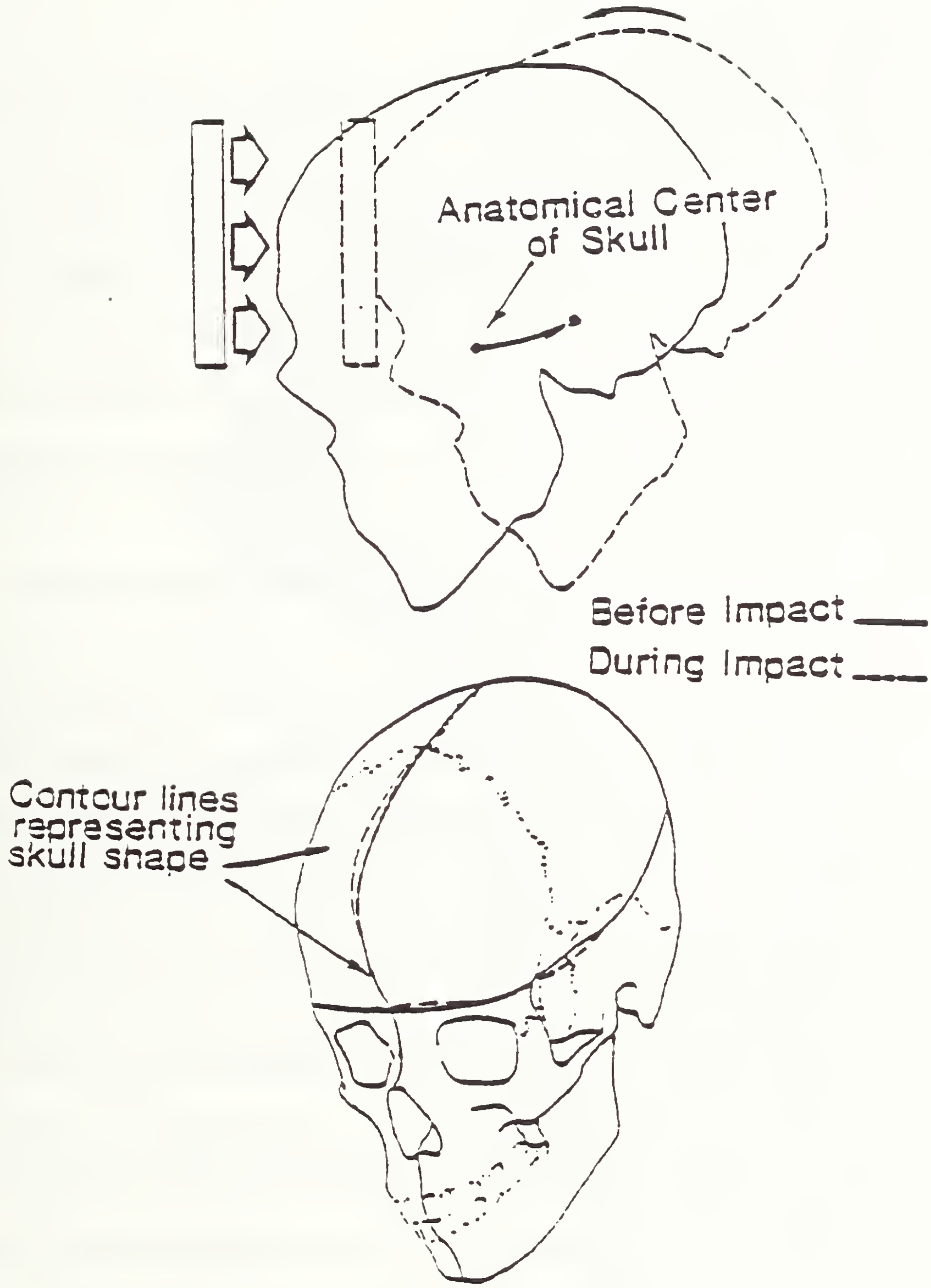
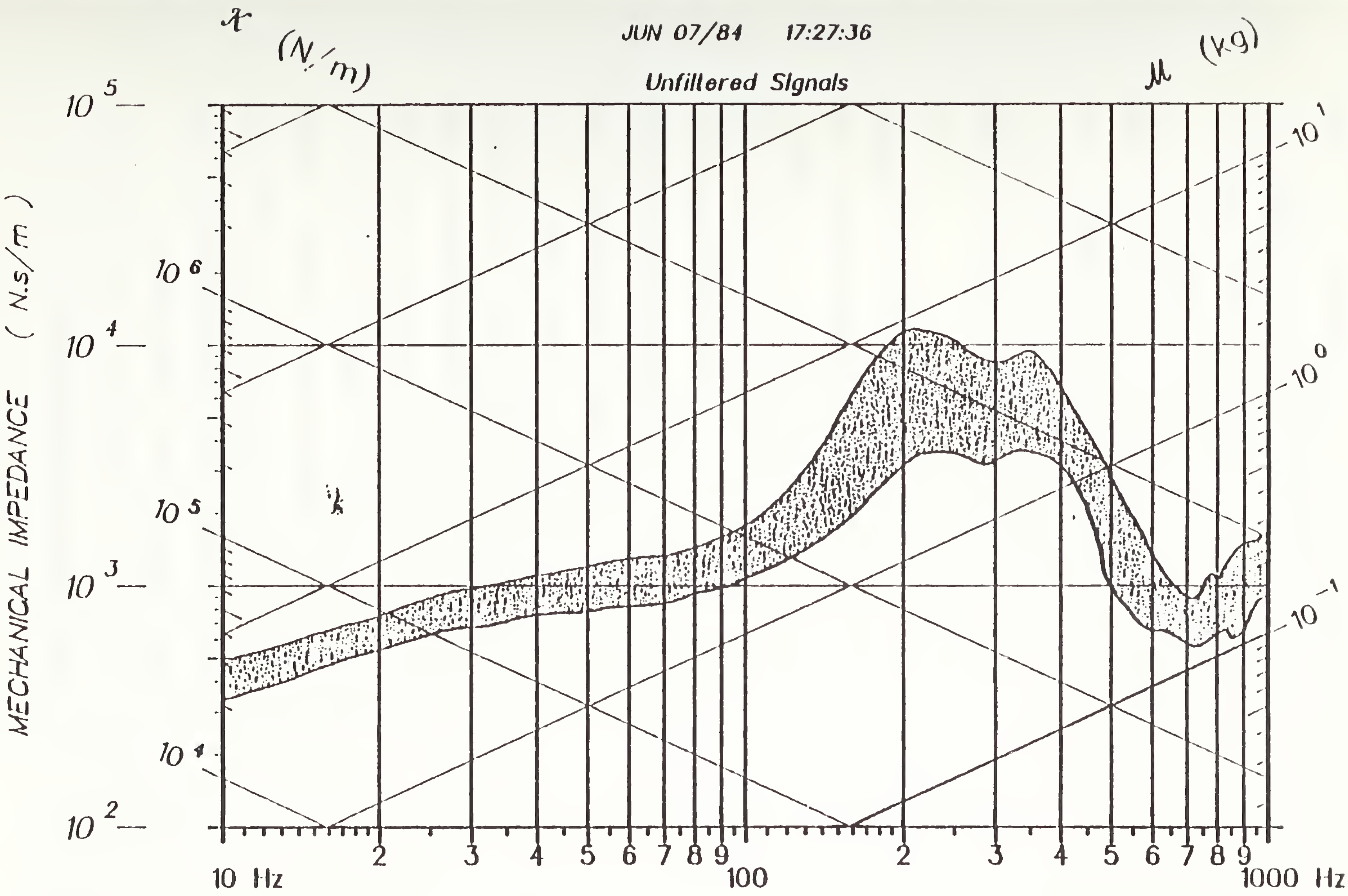


Figure 10

Effect of Skull Deformation on Angular Acceleration anatomical center" are a result of the acceleration gradient caused by the angular acceleration.

Figure 11 represents the mechanical impedance corridor of force and tangential acceleration for a test in which skull deformation was observed and no skull fracture occurred (82E021, 82E022, 82E041, 82E042, and 84E141). The impedance values for these impacts are similar to driving point impedance tests reported by other researchers [28, 64-65, 271, 308]. The skull deformation observed could be related to the same type of skull deformation obtained from the driving point impedance tests.

<u>6.6 Kinematic Response After Impact: Effect of Soft Tissue</u> - Transmission of energy during intervals Q_1-Q_2 and Q_2-Q_3 was analyzed by comparing the acceleration response of the skull to the force time-history of the impactor. The following observations were made. During the Q_1-Q_2 interval, energy was transferred from the impactor to the skull and from the skull to the brain and neck. During the Q_2-Q_3 interval, significant energy was transferred from the brain and neck to the skull. Examination of all the tests show that during the Q_2-Q_3 interval, unless there were rapid changes in the binormal vector direction (large torsion and large B-rate), the normal acceleration was established by angular acceleration. In addition, the normal and binormal vectors were established first by the angular acceleration during the Q_2-Q_3 interval and then by the angular acceleration direction changes near the Q_3 event. In general, for those tests with multimodal/unimodal peaks, the angular acceleration direction changed near the Q_2 event. The extent and amount of rotation varied from test to test. This is probably a result of the complex three-dimensional motion of the



Z=F1/V1 for

Figure 11

Mechanical Impedance Corridor for Tangential Acceleration
Skull Deformation and No Skull Fracture

head during the Q_1-Q_2 interval as well as of the geometry of the head. The rotation tends to be between pi/2 and pi radians. The motion past the Q_3 event for multimodal tangential acceleration tests is similar to the unimodal tangential acceleration test. In other words, the trajectory traced by the "estimated anatomical center" and its attached frame field during multimodal tangential acceleration impacts is different from that traced during unimodal tangential acceleration impacts. However, the motion after impact is similar when the driving force is obviously not the impactor.

In past research [308] it has been determined that in the unpressurized or partially repressurized cadaver the response of the skull after impact is influenced by differential motion of the brain. In a similar manner, with the data presented here it appears that the brain was driving the skull and that this was manifested in both a linear and rotational manner. Potentially, energy had been transferred from the skull to the brain during impact, was stored as energy and then was released as the impact force dropped below a given level.

6.7 Pressure Time-History Response - The pressure time histories were separated into two significant types, unimodal and bimodal. The unimodal pressure pulses correlate well with short-duration (less than 15ms) large-valued (1500 m/s/s and greater) tangential accelerations. Bimodal pressure pulses were more commonly observed in longer duration and lower acceleration impacts. This result seems to be a consequence of the superposition of two different types of mechanisms for producing pressure changes in the head during and after blunt impact.

The first pressure mechanism is associated with impact force time-histories which contain short-duration loading of the skull on the brain, and probably is primarily a result of inertial loading. When a blunt impact blow is delivered to the head, the skull is initially accelerated. Shortly afterwards, the brain compresses on the side closest to impact and is in tension on the side polarly distal to impact. The result is a pressure gradient in the brain encompassing the point of impact and including an area opposite from impact. Test 82E021 illustrates such pressures for selected impacts and shows that the highest magnitudes and positive pressures occur in the frontal lobe (epidural 1) and that negative pressures develop in the occipital lobe (epidural 3). Pressures in the parietal areas (epidural 2, epidural 4) are between the coup and counter coup areas. For most of these tests, the pressures in epidural 2 and epidural 4, correlated well, indicating that the pressure gradients were generally symmetric. However, some differences do exist which may be the result of three-dimensional motion of the head or of some asymmetry associated with the test subject. Figure 12 illustrates a cross- and auto-correlation between epidural 2 and epidural 4 for Tests 82E021 and 82E061 and shows that the auto-correlation for each pressure is similar to the cross-correlation, implying three-dimensional motion of the head or asymmetry of the subject This is similar to results reported by others [312-317].

Figure 13 represents transfer functions between the force and the epidural 1 and epidural 2 pressures for Tests 82E021, 82E022, 82E041 and 82E042 in which skull deformation occurred without skull fracture. These transfer functions display a resonance in the area for which a resonance was predicted from the impedance transfer function for force and acceleration. This indicates that although the exact amount of the effect of skull deformation on the pressure response is not completely

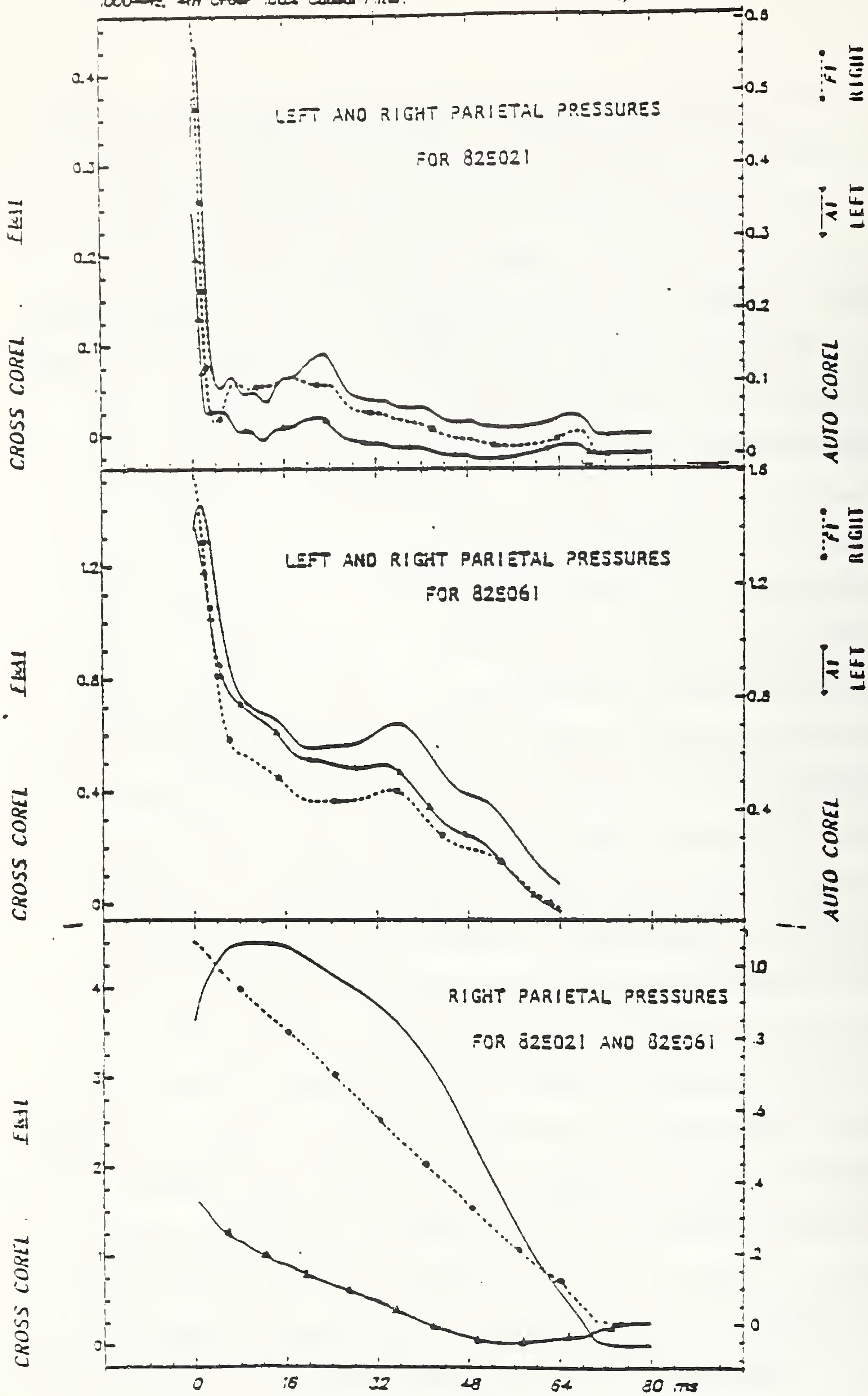
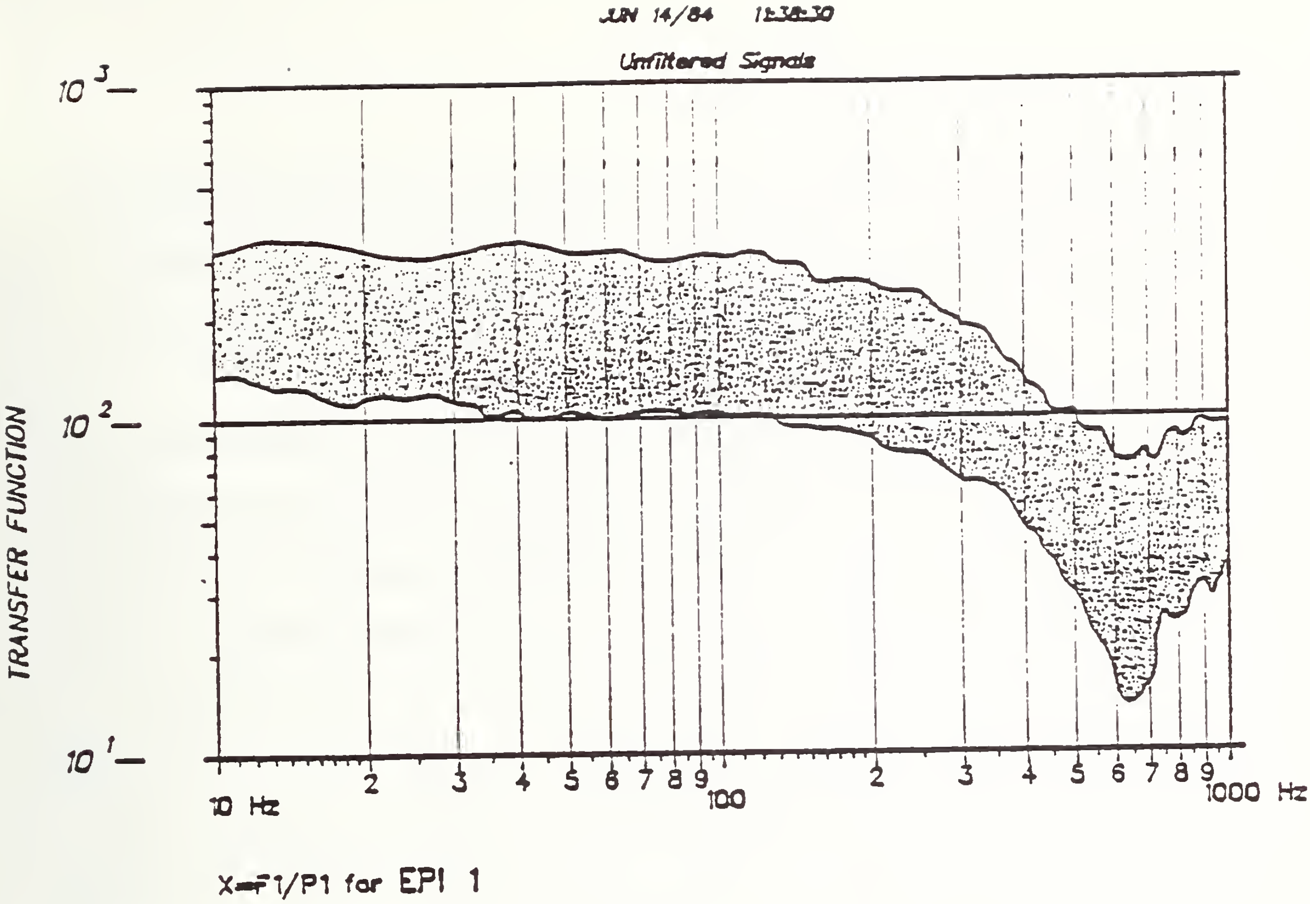


Figure 12

Cross- and Auto-Correlation for Epidural 2 and Epidural 4 Pressures



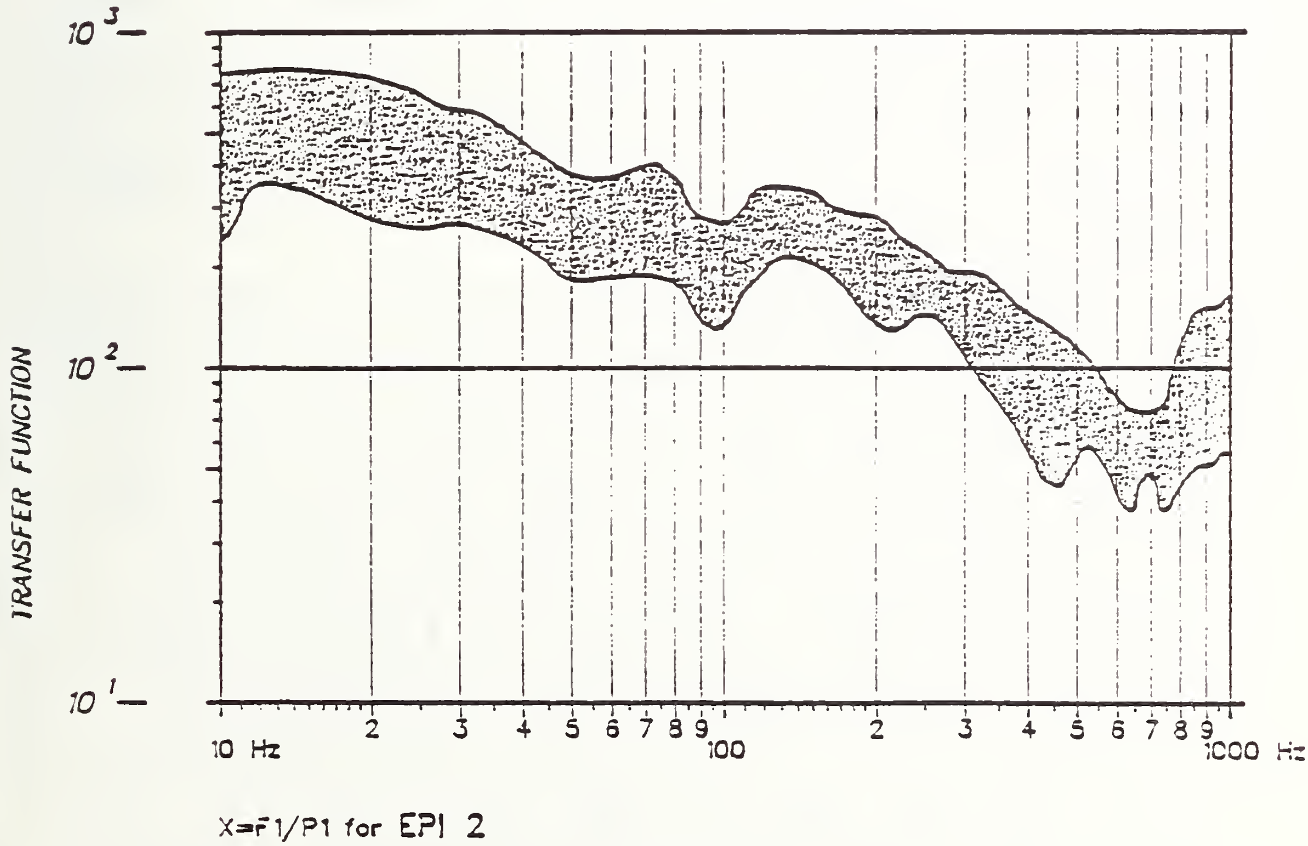


Figure 13

Transfer Functions between Force and Epidural 1 and Epidural 2 Pressures determined, it has some effect which is observable in the pressure time-history. Therefore, a reasonable correlation might be found between pressure and acceleration, although such a correlation would depend on where the accelerometers are placed on the skull.

The second pressure mechanism is associated with impact force time-histories which contain low-frequency components of motion of the head after blunt impact. Unlike the first pressure mechanism which rarely produces pressure pulses longer than 15 ms, the second pressure mechanism produces pressure pulses that can last as long as 200 ms. Possibly, the second pressure mechanism is a result of the brain driving the skull as discussed earlier. Since the pressure is positive in all transducers regardless of location, the brain may be transferring energy to the skull, thus accelerating the skull. This is consistent with the results discussed earlier where the brain stores energy and releases it shortly afterwards in a manner that is manifested by skull angular acceleration. The results obtained from the high-speed cineradiograph support this hypothesis.

<u>6.8 Injury/Damage Response</u> - The results presented in Table 4 show that the most common brain injury/damage in the repressurized cadaver is subarachnoid hemorrhage. Damage occurs for repressurized cadavers in the frontal or parietal lobes of the cerebrum. Subarachnoid hemorrhage did not occur unless "significant skull deformation" had occurred.

Identifying mechanisms of head injury poses a formidable problem. In head impact response a number of potential injury mechanisms have been proposed [190-387]. It is believed that different mechanisms occur for direct head impact than for non-impact (inertial conditions). It is also possible that several mechanisms could be responsible for producing the same injury/damage. The complex nature of the head/skull system under loading implies that during any given impact, several mechanisms could be occurring and that they may complement each other to produce injury/damage.

One possible mechanism for production of subarachnoid hemorrhage in the repressurized cadaver is induced differential motion between the skull-brain interface. Potentially, there are two types of differential motion of the skull with respect to the brain. One is associated with "local" movement of the skull differentially with respect to the brain. The second requires rotational differential motion of a "significantly large" section of the skull with respect to the brain. "Significant local acceleration" of any part of the skull may initiate differential motion of the brain surface with respect to the skull. However, because only a limited number of tests have been performed using techniques which make such observations possible, more work needs to be done before this hypothesis can be verified.

In repressurized cadaver tests, comparatively large pressure peaks were observed. It is possible that in those tests, high stress in the brain as well as skull deformations and angular accelerations were needed to produce the observed damage. In several tests, duplicate impacts were made to each subject. It is possible that this enhanced the damage response; and therefore the results presented here should not be used to set tolerance levels. However, it is believed that this did not affect the general trend of damage and/or injury response observed.

7.0 CONCLUSIONS - This was a limited study of some important kinematic factors and injury/damage modes associated with direct blunt head impact. Because of the complex nature of the skull-brain interaction during an impact event, more work is necessary before these kinematic factors can be generalized to describe head impact response. However, the following conclusions can be made:

1. "Severe impacts" to the heads of repressurized cadavers can cause local motions in the skull with or without skull fracture. The motions are interpreted as angular acceleration by nine accelerometers mounted in a single array used to determine three-dimensional motion.

2. Skull deformation may cause direct and/or indirect subarachnoid hemorrhage.

3. Three-dimensional rigid body motion is not well defined in a "severe head impact" when using accelerometers located on the skull. The acceleration time histories, including the resultant acceleration used to calculate the Head Injury Criterion (HIC), of the anatomical center, depend not only on where the accelerometers have been placed on the skull but also on the biovariability of the test subject's skull.

4. Short duration impacts (less than 15 ms) in the anterior to posterior direction appear to involve two skull-brain interactions. One occurs during impact and is characterized by a transfer of energy from the skull to the brain, and a pressure gradient in the brain positive at the frontal bone and negative at the occipital bone. The second interaction occurs during and after impact and is characterized by energy transmission from the brain to the skull and positive pressure in the brain at the frontal, parietal, and occipital bones.

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9.0 APPENDIX A

ANATOMY OF THE HEAD

OVERVIEW OF THE HEAD

SCALP

The scalp, averaging 5 to 7 mm in thickness, consists not only of the hair and skin but also of layered soft tissues between the skin and the skull. When a traction force is applied to the scalp, its outer three layers (the hair-and-skin layer, a subcutaneous connective tissue layer, and a muscle and facial layer) move together as one. Next there is a loose connective tissue layer plus the fibrous membrane which covers bone (the periosteum). The thickness, firmness, and mobility of the outer three layers of scalp function as protective features.

SKULL

The skull is the most complex structure of the skeleton because bone is neatly molded around and fitted to the brain, eyes, ears, nose and teeth. The thickness of the skull varies between 4-7 mm, snugly accommodating these components of the head and reinforcing the strength of the skull. The skull is composed of eight bones which form the brain case and fourteen bones which form the face plus the teeth. Excluding the face, the cranial vault (calvarium) is formed by the ethmoid, sphenoid, frontal, two temporal, two parietal, and occipital bones. The inner surface of the cranial vault is concave and relatively smooth. The base of the brain case is a thick irregular plate of bone containing depressions and ridges plus small holes for arteries, veins, nerves, and the large hole (the foramen magnum), which is the transition area between the spinal cord and the brain.

THE MEMBRANES MENINGES

Three membranes known as the meninges protect and support the brain and spinal cord (which together comprise the central nervous system).

The meninges separate the brain and spinal cord from the bones which surround them. Consisting primarily of connective tissue, the meninges also form part of the walls of blood vessels and the sheaths of nerves as they emerge from their bony covering.

The membranes meninges are known individually as the dura mater, the arachnoid, and the pia mater. The dura mater is a heavy, tough membrane that surrounds the spinal cord and brain. In the skull it is divided into two layers. The outer cranial layer of dura mater, the periosteal layer, lines the inner surface of the calvarium. The inner layer of cranial dura mater, the meningeal layer, covers the brain. In the brain case, the two layers of dura mater are closely united except where they separate to form sub-structures such as the venous sinuses which drain blood from the brain, the falx cerebri, a fold of the inner layer of dura mater which projects into the longitudinal fissure between the right and left cerebral hemispheres, and the tentorium cerebelli, a fold of the inner layer of dura mater forming a shelf on which the posterior cerebral hemispheres are supported.

The arachnoid layer is a delicate spider web-like membrane which is separated from the dura mater by a narrow space called the subdural space which contains a thin film of watery fluid known as cerebrospinal fluid. In the superior longitudinal sinus (sagittal sinus) and transverse sinuses, the arachnoid mater forms structures called arachnoid granulations which reabsorb cerebrospinal fluid into the blood. The arachnoid mater extends down the spinal canal to the level of the second sacral vertebra where it surrounds the terminal filament of the spinal cord.

The pia mater is a thin membrane of fine connective tissue filled with numerous small blood vessels. It is separated from the arachnoid by a space filled with cerebrospinal fluid known as the subarachnoid space. The pia mater covers the surface of the brain, dipping well into its furrows. The pia mater covering the spinal cord is thicker than the cranial pia mater and it becomes the terminal filament of the spinal cord.

CEREBROSPINAL FLUID

The subarachnoid space and the ventricles of the brain are filled with a clear, watery, colorless fluid (cerebrospinal fluid/CSF), which provides some nutrients for the brain and which cushions the brain from mechanical shock. For normal movement, a shrinking or expanding of the brain is quickly balanced by an increase or decrease of CSF. The specific gravity of cerebrospinal fluid is about 1.008 in the adult. About 140 ml of CSF constantly circulates so that it surrounds the brain on all sides, serving as a buffer and helping to support the brain's weight. Since the subarachnoid space of the brain is continuous with that of the spinal cord, the spinal cord is suspended in a tube of CSF.

CENTRAL NERVOUS SYSTEM

Microscopically, the central nervous system is largely a network of neurons and supportive tissue functionally arranged into areas which are gray or white in color. Named for this color distinction, gray matter is composed primarily of nerve cell bodies concentrated in locations on the surface of the brain and also deep within the brain; white matter is composed of myelinated nerve cell processes which primarily form tracts to connect parts of the central nervous system to each other. There is a difference in density between gray matter and white matter. Macroscopically, the CNS is the brain and the spinal cord.

THE BRAIN

The brain is structurally and functionally five parts--cerebrum, cerebellum, midbrain, pons, and medulla oblongata plus four ventricles (CSF cisterns with exits); three membranes (meninges); two glands (pituitary and pineal); twelve pairs of cranial nerves; and the cranial arteries and veins. The brain snugly fills the cranial cavity. The average length of the brain is about 165 mm and its greatest transverse diameter is about 140 mm. Due to dimorphic differences, its average mass is 1360 gm for males and a little less for females. The adult brain represents about 2 percent of the weight of the body. The specific gravity of the brain averages 1.036 and it is gelatinous in consistency. The brain constitutes 98 percent of the central nervous system. The adult brain represents about 2 percent of the weight of the body. Looking down on the brain from above, the cerebrum is two cerebral hemispheres which conceal the rest of the brain. Behind and below the cerebral hemispheres lie the two hemispheres of the cerebellum. Beneath the cerebrum and cerebellum are the smaller midbrain, pons, and medulla oblongata.

CEREBRUM

The cerebrum is 7/8 ths of the brain's mass, and is hemisected into right and left cerebral hemispheres. These are incompletely separated by a deep midline cleft called the longitudinal cerebral fissure. The falx cerebri projects downwards into this fissure. Beneath the longitudinal cerebral fissure the two cerebral hemispheres are connected by a mass of white matter called the corpus callosum.

Within each cerebral hemisphere is a cistern for cerebrospinal fluid called the <u>lateral ventricle</u>. Each cerebral hemisphere has a surface layer of gray matter called the <u>cerebral cortex</u>. The cerebral cortex is arranged into a number of folds, which are separated by fissures. These fissures further separate the cerebral hemispheres into lobes so that each hemisphere is divided into four lobes, each lobe being named by its association to the nearest cranial bone. Thus, the four lobes are the frontal, parietal, temporal and occipital lobes.

The interior of each cerebral hemisphere is composed of white matter or nerve fibers. These are arranged in tracts and serve to connect one part of a cerebral hemisphere with another, or to connect the cerebral hemispheres to each other, or to connect the cerebral hemispheres to the other parts of the central nervous system. In addition, within these interior areas of white matter are a number of areas of gray matter.

MIDBRAIN

The midbrain connects the cerebral hemispheres above to the pons below. Anteriorly the midbrain is composed of two stalks which are mainly fibers passing to and from the cerebral hemispheres above. Within the midbrain is a narrow canal which connects the third ventricle above to the fourth ventricle below.

PONS

The pons lies below the midbrain, in front of the cerebellum and above the medulla oblongata. It is composed of white matter nerve fibers connecting the cerebellar hemispheres. Lying deeply within its white matter are areas of gray matter which are nuclei for some of the cranial nerves.

MEDULLA OBLONGATA

The medulla oblongata appears continuous with the pons above and the spinal cord below. In the lower part of the medulla oblongata motor fibers cross from one side to the other so that fibers from the right cerebral cortex pass to the left side of the body. Some sensory fibers passing upwards towards the cerebral cortex also cross from one side to the other in the medulla oblongata. The medulla oblongata also contains areas of gray matter within its white matter. These are nuclei for cranial nerves and relay stations for sensory fibers passing upwards from the spinal cord.

CEREBELLUM

The cerebellum lies behind the pons and the medulla oblongata. Its two hemispheres are joined at the midline by a narrow strip-like structure called the vermis. The outer cortex of the cerebellar hemispheres is gray matter; the inner cortex is white matter. The outer surface of the cerebellum forms into narrow folds separated by deep fissures. Nerve fibers enter the cerebellum in three pairs of stalks which connect the cerebellar hemispheres to the midbrain, pons, and the medulla oblongata.

SPINAL CORD

The spinal cord comprises 2 percent of the central nervous system and averages 45 cm in length. Thirty-one pairs of nerves arise from the spinal cord. The spinal cord is protected by the spinal column, the membranes meninges, and pressurized CSF. The spinal dura mater forms a one-layer loose protective covering for the spinal cord and corresponds to the inner layer of cranial dura mater. The space between the bones of the spinal column and the dura mater, the <u>extradural space</u>, is filled with fat and a venous network.

10.0 APPENDIX B
TEST PROTOCOL

DEPARTMENT OF TRANSPORTATION

MULTIPLE IMPACT TESTS

_______ Through _______

as performed by

the Biomechanics Department of

the Highway Safety Research Institute

Ann Arbor, Michigan

1982-1983 E Series

This protocol for the use of cadavers in this test series was approved by the Committee to Review Grants for Clinical Research of the University of Michigan Medical Center and follows guidelines established by the U.S. Public Health Service and those recommended by the National Academy of Sciences, National Research Council.

TABLE OF CONTENTS

TEST DESCRIPTION

Cadaver No.________ Sex:_____ Height:_____ Weight:_____

Test No.__________ (Head, Shoulder, Pelvis)

Test description: Head impact, subject in a normal seated position, neck angle approx. 10° forward, impact to forehead, angle of head determined by tangent forehead plane.

Type of Impactor: PENDULUM

Type of Bumper: WHITE VIBRATHANE

Type of Striker: 25 Kg PISTON, 15cm DIA.

Impactor Angle: 50°(5.0m/s)

Padding:________________________________

Pre-Impact Travel: 14cm

Post-Impact Travel: 16cm

35mm stills:

___ Black and White

___ Color

CAMERAS		POSITION
Photosonics 1:	1000	P-A, S-I
Photosonics 2:		
HyCam:	3000	P-A, S-I

Test Description - 2

INSTRUMENTATION

ACCELEROMETERS		TARGETS		TRANSDUCERS	
Head (9 AX)	X	Head	X	Trachea	
Up. Sternum (3-AX)		Acromion	X	Ascending Aorta	
Lwr. Sternum (1)		Sternum (2)		Internal Carotid	X
Spine (2 triax)	X	Spine			
Pelvis (9 AX)		Pelvis		Subdural 1:	X
Lwr. Rib R8 (2)				2:	X
Up. Rib R4 (2 triax)				3:	X
				4:	?

Test Description - 3

TEST DESCRIPTION

Cadaver No.________ Sex:_____ Height:_____ Weight:_____

Test No.__________ (Head, Shoulder, Pelvis)

Test description:
Head impact, same as previous.

Type of Impactor: PENDULUM

Type of Bumper: WHITE VIBRATHANE

Type of Striker: 25 Kg PISTON, 15cm DIA.

Impactor Angle: 50°(5.0m/s)

Padding:____________________

Pre-Impact Travel: 14cm

Post-Impact Travel: 16cm

35mm stills:

___ Black and White

___ Color

CAMERAS		POSITION
Photosonics 1:	1000	P-A, S-I
Photosonics 2:		
HyCam:	3000	P-A, S-I

Test Description - 4

INSTRUMENTATION

ACCELEROMETERS		TARGETS		TRANSDUCERS	
Head (9 AX)	X	Head	X	Trachea	
Up. Sternum (3-AX)		Acromion	X	Ascending Aorta	
Lwr. Sternum (1)		Sternum (2)		Internal Carotid	X
Spine (2 triax)	X	Spine			
Pelvis (9 AX)		Pelvis		Subdural	1: X
Lwr. Rib R8 (2)					2: X
Up. Rib R4 (2 triax)					3: X
					4: ?

COMMENTS:

TEST DESCRIPTION

Cadaver No.________ Sex:_____ Height:_____ Weight:_____

Test No.__________ (Head, Shoulder, Pelvis)

Test description: Front tap, mid-sternum, angle of thorax determined by sternum tangent plane, top of impact 54 cm from seat pan.

Type of Impactor: PENDULUM

Type of Bumper: WHITE VIBRATHANE

Type of Striker: 25 Kg PISTON, 21cm. sq.

Impactor Angle: 17°(2m/s)

Padding: .5cm ensolite

Pre-Impact Travel: 8cm

Post-Impact Travel: 22cm

35mm stills:

___ Black and White

___ Color

CAMERAS		POSITION
Photosonics 1:	1000	P-A, S-I
Photosonics 2:		
HyCam:	3000	P-A, S-I

INSTRUMENTATION

ACCELEROMETERS		TARGETS		TRANSDUCERS	
Head (9-AX)	X	Head	X	Trachea	X
Up. Sternum (3-AX)	X	Acromion	X	Ascending Aorta	X
Lwr. Sternum (1)	X	Sternum (2)	X	Internal Carotid	___
Spine (2 triax)	X	Spine	___		
Pelvis (9-AX)	___	Pelvis	___	Subdural 1:	___
Lwr. Rib R8 (2)	X			2:	___
Up. Rib R4 (2 triax)	X			3:	___
				4:	___

COMMENTS:

TEST DESCRIPTION

Cadaver No.________ Sex:_____ Height:_____ Weight:_____

Test No.__________ (Head, Shoulder, Pelvis)

Test description: Left side tap, 45°P-A into R-L, normal seated posture, move arm if necessary, top of impact 54 cm above seat pan.

Type of Impactor: PENDULUM

Type of Bumper: WHITE VIBRATHANE

Type of Striker: 25 Kg PISTON, 21cm. sq.

Impactor Angle: 17°(2m/s)

Padding: .5cm ensolite

Pre-Impact Travel: 8cm

Post-Impact Travel: 22cm

35mm stills:

___ Black and White

___ Color

CAMERAS		POSITION
Photosonics 1:	1000	45° P-A into R-L, S-I
Photosonics 2:		
HyCam:	3000	45° P-A into R-L, S-I

INSTRUMENTATION

ACCELEROMETERS		TARGETS		TRANSDUCERS	
Head (9-AX)	X	Head	X	Trachea	X
Up. Sternum (3-AX)	X	Acromion	X	Ascending Aorta	X
Lwr. Sternum (1)	X	Sternum (2)	X	Internal Carotid	___
Spine (2 triax)	X	Spine	___		
Pelvis (9-AX)	___	Pelvis	___	Subdural	1: ___
Lwr. Rib R8 (2)	X				2: ___
Up. Rib R4 (2 triax)	X				3: ___
					4: ___

COMMENTS:

TEST DESCRIPTION

Cadaver No.________ Sex:_____ Height:_____ Weight:_____

Test No.__________ (Head, Shoulder, Pelvis)

Test description: Left side tap arms up, position arms to minimize interference from scapula as well as centering piston in the R-L/I-S plane, normal seated posture. Top of impact 54 cm above seat pan. (This test may be dropped.)

Type of Impactor: PENDULUM

Type of Bumper: WHITE VIBRATHANE

Type of Striker: 25 Kg PISTON, 21cm sq.

Impactor Angle: 17°(2m/s)

Padding: .5cm ensolite

Pre-Impact Travel: 8cm

Post-Impact Travel: 22cm

35mm stills:

___ Black and White

___ Color

CAMERAS		POSITION
Photosonics 1:	1000	R-L, S-I
Photosonics 2:		
HyCam:	3000	R-L, S-I

INSTRUMENTATION

ACCELEROMETERS		TARGETS		TRANSDUCERS	
Head (9-AX)	X	Head	X	Trachea	X
Up. Sternum (3-AX)	X	Acromion	X	Ascending Aorta	X
Lwr. Sternum (1)	X	Sternum (2)	X	Internal Carotid	
Spine (2 triax)	X	Spine			
Pelvis (9-AX)		Pelvis		Subdural 1:	
Lwr. Rib R8 (2)	X			2:	
Up. Rib R4 (2 triax)	X			3:	
				4:	

COMMENTS:

TEST DESCRIPTION

Cadaver No.________ Sex:_____ Height:_____ Weight:_____

Test No.__________ (Head, Shoulder, Pelvis)

Test description: Left side tap arms down, normal seated posture, in the R-L/I-S plane, top of impact 54 cm above seat pan.

Type of Impactor: PENDULUM

Type of Bumper: WHITE VIBRATHANE

Type of Striker: 25 Kg PISTON, 21cm sq.

Impactor Angle: 17°(2m/s)

Padding: .5cm ensolite

Pre-Impact Travel: 8cm

Post-Impact Travel: 22cm

35mm stills:

___ Black and White

___ Color

CAMERAS		POSITION
Photosonics 1:	1000	R-L, S-I
Photosonics 2:		
HyCam:	3000	R-L, S-I

INSTRUMENTATION

ACCELEROMETERS		TARGETS		TRANSDUCERS	
Head (9-AX)	X	Head	X	Trachea	X
Up. Sternum (3-AX)	X	Acromion	X	Ascending Aorta	X
Lwr. Sternum (1)	X	Sternum (2)	X	Internal Carotid	___
Spine (2 triax)	X	Spine	___		
Pelvis (9-AX)	___	Pelvis	___	Subdural	1: ___
Lwr. Rib R8 (2)	X				2: ___
Up. Rib R4 (2 triax)	X				3: ___
					4: ___

COMMENTS:

TEST DESCRIPTION

Cadaver No.________ Sex:_____ Height:_____ Weight:_____

Test No.__________ (Head, Shoulder, Pelvis)

Test description: Left side impact, same as left side arms down tap.

Type of Impactor: PENDULUM

Type of Bumper: WHITE VIBRATHANE

Type of Striker: 25 Kg PISTON, 21cm sq.

Impactor Angle: 100°(8.8m/s)

Padding: 15cm APR pads

Pre-Impact Travel: 9cm

Post-Impact Travel: 21cm

35mm stills:

___ Black and White

___ Color

CAMERAS		POSITION
Photosonics 1:	1000	R-L,S-I
Photosonics 2:		
HyCam:	3000	R-L, S-I

INSTRUMENTATION

ACCELEROMETERS		TARGETS		TRANSDUCERS	
Head (9-AX)	X	Head	X	Trachea	X
Up. Sternum (3-AX)	X	Acromion	X	Ascending Aorta	X
Lwr. Sternum (1)	X	Sternum (2)	X	Internal Carotid	___
Spine (2 triax)	X	Spine	___		
Pelvis (9-AX)	___	Pelvis	___	Subdural	1:___
Lwr. Rib R8 (2)	X				2:___
Up. Rib R4 (2 triax)	X				3:___
					4:___

COMMENTS:

TEST DESCRIPTION

Cadaver No.________ Sex:_____ Height:_____ Weight:_____

Test No.________ (Head, Shoulder, Pelvis)

Test Description: Pelvic impact, right side, 8cm anterior to trochanterion, centered on femur.

Type of Impactor: PENDULUM

Type of Bumper: WHITE VIBRATHANE

Type of Striker: 25 Kg PISTON, 15cm DIA.

Impactor Angle: 100°(8.8m/s)

Padding: .5cm ensolite

Pre-Impact Travel: 12cm

Post-Impact Travel: 18cm

35mm stills:

___ Black and White

___ Color

CAMERAS		POSITION
Photosonics 1:	1000	R-L, S-I
Photosonics 2:		
HyCam:	3000	R-L, S-I

INSTRUMENTATION

ACCELEROMETERS		TARGETS		TRANSDUCERS	
Head (9-AX)	___	Head	___	Trachea	___
Up. Sternum (3-AX)	___	Acromion	___	Ascending Aorta	___
Lwr. Sternum (1)	___	Sternum (2)	___	Internal Carotid	___
Spine (2 triax)	X	Spine	X		
Pelvis (9-AX)	X	Pelvis	X	Subdural 1:	___
Lwr. Rib R8 (2)	___			2:	___
Up. Rib R4 (2 triax)	___			3:	___
				4:	___

COMMENTS:

TEST DESCRIPTION

Cadaver No.________ Sex:_____ Height:_____ Weight:_____

Test No.__________ (Head, Shoulder, Pelvis)

Test description:____

____

____

____

____

Type of Impactor:________________

Type of Bumper:________________

Type of Striker:________________

Impactor Angle:________________

Padding:________________________

Pre-Impact Travel:______________

Post-Impact Travel:_____________

35mm stills:

___ Black and White

___ Color

CAMERAS		POSITION
Photosonics 1:	__________	____________
Photosonics 2:	__________	____________
HyCam:	__________	____________

INSTRUMENTATION

ACCELEROMETERS		TARGETS		TRANSDUCERS	
Head (9-AX)	___	Head	___	Trachea	___
Up. Sternum (3-AX)	___	Acromion	___	Ascending Aorta	___
Lwr. Sternum (1)	___	Sternum (2)	___	Internal Carotid	___
Spine (2 triax)	___	Spine	___		
Pelvis (9-AX)	___	Pelvis	___	Subdural	1:___
Lwr. Rib R8 (2)	___				2:___
Up. Rib R4 (2 triax)	___				3:___
					4:___

COMMENTS:

TEST DESCRIPTION

Cadaver No.________ Sex:_____ Height:_____ Weight:_____

Test No.__________ (Head, Shoulder, Pelvis)

Test description:____

____

____

____

____

Type of Impactor:________________

Type of Bumper:__________________

Type of Striker:_________________

Impactor Angle:__________________

Padding:_________________________

Pre-Impact Travel:_______________

Post-Impact Travel:______________

35mm stills:

___ Black and White

___ Color

CAMERAS		POSITION
Photosonics 1:	__________	____________
Photosonics 2:	__________	____________
HyCam:	__________	____________

INSTRUMENTATION

ACCELEROMETERS		TARGETS		TRANSDUCERS	
Head (9-AX)	___	Head	___	Trachea	___
Up. Sternum (3-AX)	___	Acromion	___	Ascending Aorta	___
Lwr. Sternum (1)	___	Sternum (2)	___	Internal Carotid	___
Spine (2 triax)	___	Spine	___		
Pelvis (9-AX)	___	Pelvis	___	Subdural	1:___
Lwr. Rib R8 (2)	___				2:___
Up. Rib R4 (2 triax)	___				3:___
					4:___

COMMENTS:

TEST DESCRIPTION

Cadaver No.________ Sex:_____ Height:_____ Weight:_____

Test No.__________ (Head, Shoulder, Pelvis)

Test description:____

____

____

____

____

Type of Impactor:_______________

Type of Bumper:_________________

Type of Striker:________________

Impactor Angle:_________________

Padding:________________________

Pre-Impact Travel:______________

Post-Impact Travel:_____________

35mm stills:

___ Black and White

___ Color

CAMERAS		POSITION
Photosonics 1:	__________	____________
Photosonics 2:	__________	____________
HyCam:	__________	____________

INSTRUMENTATION

ACCELEROMETERS		TARGETS		TRANSDUCERS	
Head (9-AX)	___	Head	___	Trachea	___
Up. Sternum (3-AX)	___	Acromion	___	Ascending Aorta	___
Lwr. Sternum (1)	___	Sternum (2)	___	Internal Carotid	___
Spine (2 triax)	___	Spine	___		
Pelvis (9-AX)	___	Pelvis	___	Subdural	1:___
Lwr. Rib R8 (2)	___				2:___
Up. Rib R4 (2 triax)	___				3:___
					4:___

COMMENTS:

PRE-SURGERY

TASK	TIME	COMMENTS
Pick up cadaver from U of M Anatomy Dept. and transport to HSRI Biomedical lab.		
Weigh cadaver and log cadaver information.		
Store cadaver if necessary.		
Sanitary preparation.		
Pretest X-rays: (KV/MA/T) head A-P (100/10/1) ___/___/___ thorax A-P (90/10/1) ___/___/___ thorax A-P(2) (90/10/1) ___/___/___ pelvis (105/10/1) ___/___/___ femur (80/10/1) ___/___/___		
Anthropometry.		

ANTHROPOMETRY

Height:__________

Weight:__________

Sex:__________

Age:__________

Stature: left:__________ right:__________

Suprasternale height:__________

Substernale height:__________

Substernale depth:__________

Substernale breadth:__________

Substernale circumference:__________

Vertex to 12th rib:__________

Head to C7:__________

Mastoid to vertex: left:__________ right:__________

Tragon to vertex: left:__________ right:__________

Menton to vertex:__________

Bitragon diameter:__________

Acromion height: left:__________ right:__________

Acromion to tip of finger:__________

Biacromion:__________

Axillary breadth:__________

Axillary depth:__________

Axillary circumference:__________

Head breadth (R-L):__________

Head depth (A-P):__________

Head circumference:__________

Neck circumference:__________

Bitrochanteric breadth:__________

Symphysion depth:__________

Vertex to Symphysion:__________

Bispinous (ASIS) diameter:__________

Biiliocristale breadth:__________

ASIS to Symphysion:__________

Anatomical Anomalies / Clinical Observations

1. Head: a. Brain b. Skull

2. Neck:

3. Thorax: a. Ribs b. Heart c. Lungs d. Diaphragm

4. Pelvis:

5. Femur

6. Abdomen

RIB AND STERNUM MOUNTS

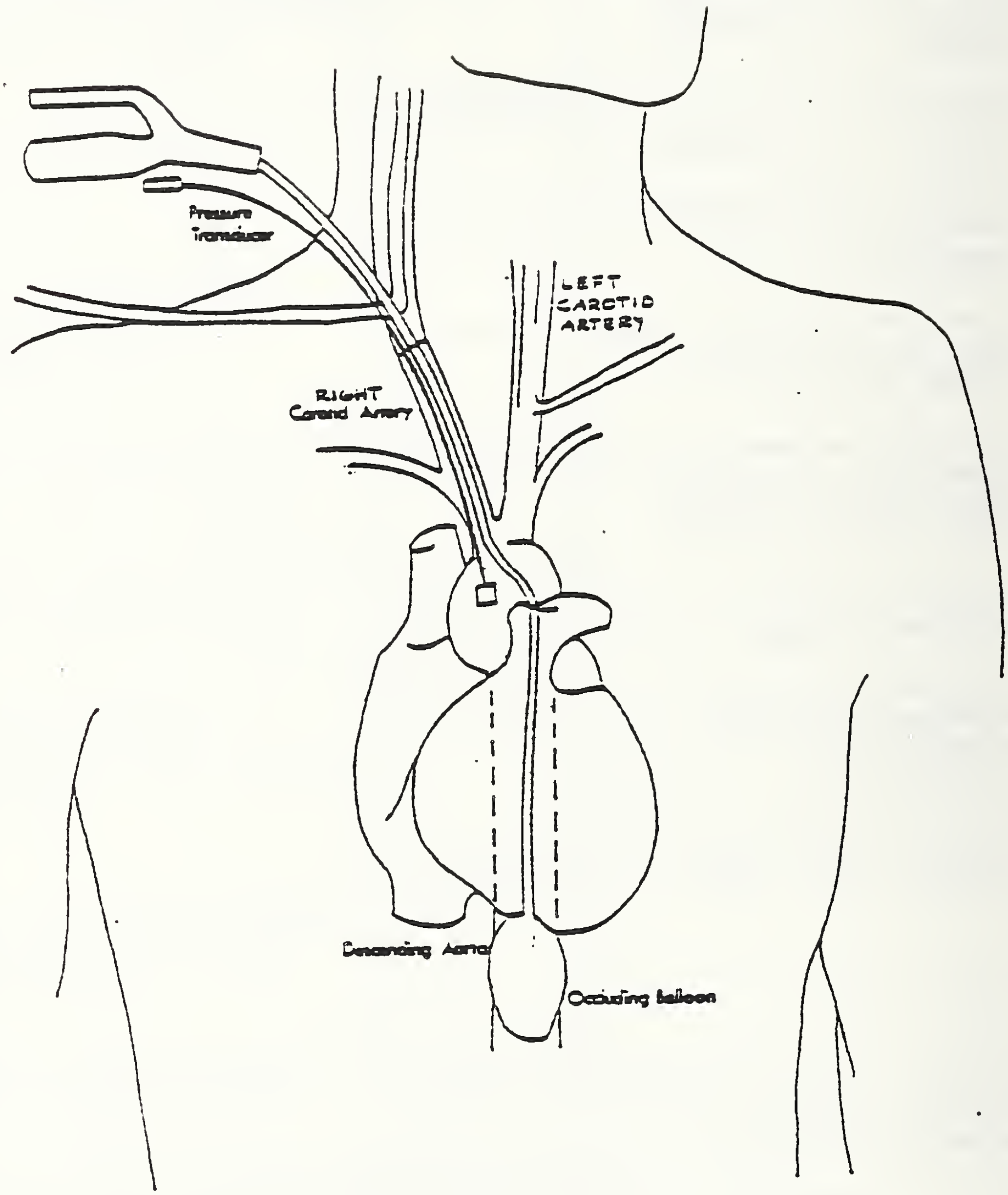
TASK	TIME	COMMENTS
Locate right and left R4 by palpation.		
Make incisions over ribs near flat region. Surface must be normal to the R-L vector.		
Loop two pieces of wire (1/2" apart) around each rib.		
Locate R8 by counting down from R4 and up from R12.		
Make incision over rib near flat region. Surface must be normal to the R-L vector.		
Make incisions over suprasternale and substernale.		
Secure mounts to rib by anchoring with pins and wire.		
Screw lag bolt into each acromion.		

PRESSURIZATION

TASK	TIME	COMMENTS
Locate right carotid and cut lengthwise.		
Locate right vertebral artery and ligate.		
Loop six pieces of string around carotid artery.		
Insert fabricated Foley catheter (#18 or #20) into descending aorta.		
Insert Kulite shield into ascending aorta.		
Insert Kulite shield into carotid artery.		
Insert arterial pressurization catheters into carotid artery.		
Using syringe, squirt acrylic into artery. Tie and sew.		
Locate left carotid, cut, loop strings.		
Locate left vertebral artery and ligate.		

PRESSURIZATION (CONT'D)

TASK	TIME	COMMENTS
Insert arterial pressurization catheters (#10, #12, or #14) into carotid artery.		
Acrylic, tie and sew.		
Locate trachea and cut lengthwise.		
Loop two Tie Wraps around trachea.		
Insert polyethelyne tube snugly, tie and sew.		
Calibrate lungs.		
Pulmonary pressure relief valve calibration.		
Vascular flow check.		
Sternal geometry if necessary.		



Pressure
Transducer
LEFT
CAROTID
ARTERY
RIGHT
Carotid Artery
Descending Aorta
Occluding balloon

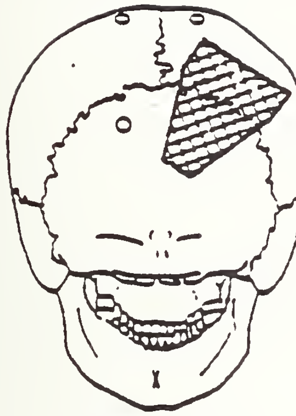
B34

HEAD 9-AX MOUNT

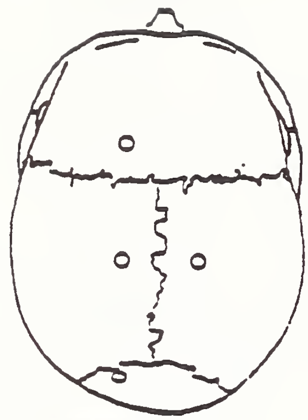
TASK	TIME	COMMENTS
With cadaver facing down, remove a 2x2" area of scalp spanning the right parietal and occipital bones.		
Drill three holes in a triangular pattern, approximately the size of the 9-ax plate.		
Insert three screws.		
Attach four feet to the 9-ax plate such that three of the feet can be positioned near the screws on the exposed forehead.		
Place acrylic around screws.		
Place plate on top of acrylic base, making sure the acrylic goes through the center holes in the plate.		
Insert a strain relief bolt in the acrylic base of the head platform. Make sure bolt does not contact plate.		

HEAD TRANSDUCERS

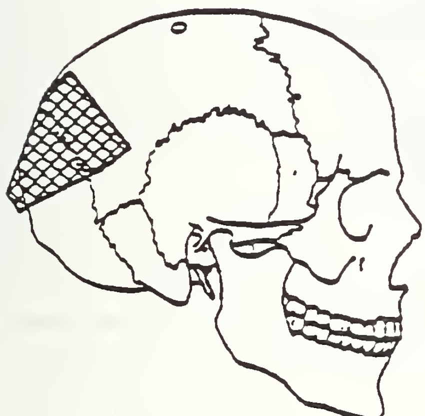
TASK	TIME	COMMENTS
Holes for transducers go on frontal, parietal, and occipital bones. Make sure no Xducers will contact the impacting surface. Also, the holes should not be drilled into suture.		
To drill holes, remove a 1/4" dia. circle of scalp.		
Drill through skull with a #7 drill. Be sure not to drill through the dura.		
Perforate the dura without cutting brain.		
Tap hole with a No.7 tap.		
Pinhead screws are attached 2cm from each transducer. Acrylic is applied to each area, carefully molding around the transducers.		
Note positions of head transducers on the figure.		



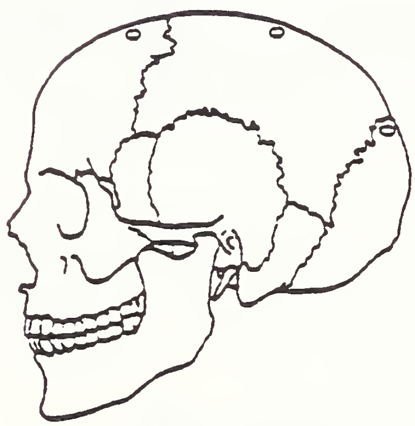
Posterior View



Superior View



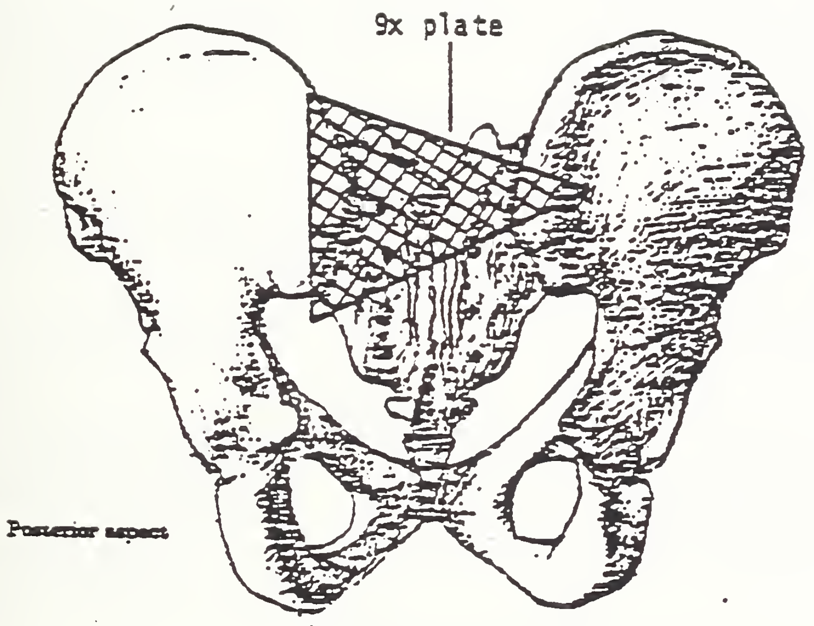
Right Lateral View



Left Lateral View

PELVIS MOUNT

TASK	TIME	COMMENTS
Locate the posterior-superior iliac spines.		
Screw two lag bolts into each spine such that the large 9-ax plate spans the bolts.		
Attach four feet to the plate such that the feet are near the lag bolts.		
Place acrylic around screws and feet.		
Imbed feet and posterior surface into acrylic.		
Test plate to see that it is secure.		



B39

SPINAL MOUNTS

TASK	TIME	COMMENTS
Spinal mounts go on T1 and T12.		
Make incisions over T1 and T12. Clear muscle and tissue away from process, but do not cut between processes.		
Drill a small hole 1/4" deep in each process.		
Screw mounts on with wood screws (be sure screws are in process).		
Place stabilizing and mooring probic devices on each side of the laminae. Secure with Tie Wraps.		
Mold acrylic around (and under) mounts and mooring devices and allow to dry.		
Make sure accelerometers are anatomically oriented.		
Spinal geometry if necessary.		

CEREBROSPINAL PRESSURIZATION

TASK	TIME	COMMENTS
Locate L2 by palpation and counting from T12.		
Core a small hole in the lamina.		
Insert Foley catheter (#14 or #16) such that balloon is in mid-thorax.		
Insert small screws in lamina and process.		
Seal off hole with acrylic.		
Check for structural integrity of vertebra.		
Cerebral-spinal flow check.		
Check pressurization.		

PREPARATION

TASK	TIME	COMMENTS
Dress cadaver.		
Place head and body harnesses on cadaver.		
Store cadaver if necessary.		
Transport cadaver to sled lab, being careful not to damage mounts.		
Place head, sternum, and rib transducers on cadaver. Stuff and sew.		
Set up pressurization equipment (pulmonary, cerebro-spinal, vascular head and vascular thorax).		

ELECTRONICS CHECK AND PRETEST TRIAL RUN

Electronics Check

- ___ check accelerometers (excitation and zero)
- ___ check wiring and cables
- ___ mount accelerometers in triax clusters
- ___ check amplifiers
- ___ calibrate tape with impedance-matching amp
- ___ recorder
- ___ complete wiring
- ___ check pendulum accelerometer
- ___ check velocity, strobe, gate, timer, rope cutters
- ___ run trial test
- ___ load cell mounted on pendulum day before test
- ___ load Photosonics and HyCam cameras with Kodak 16mm 7242-#FB-430 color film

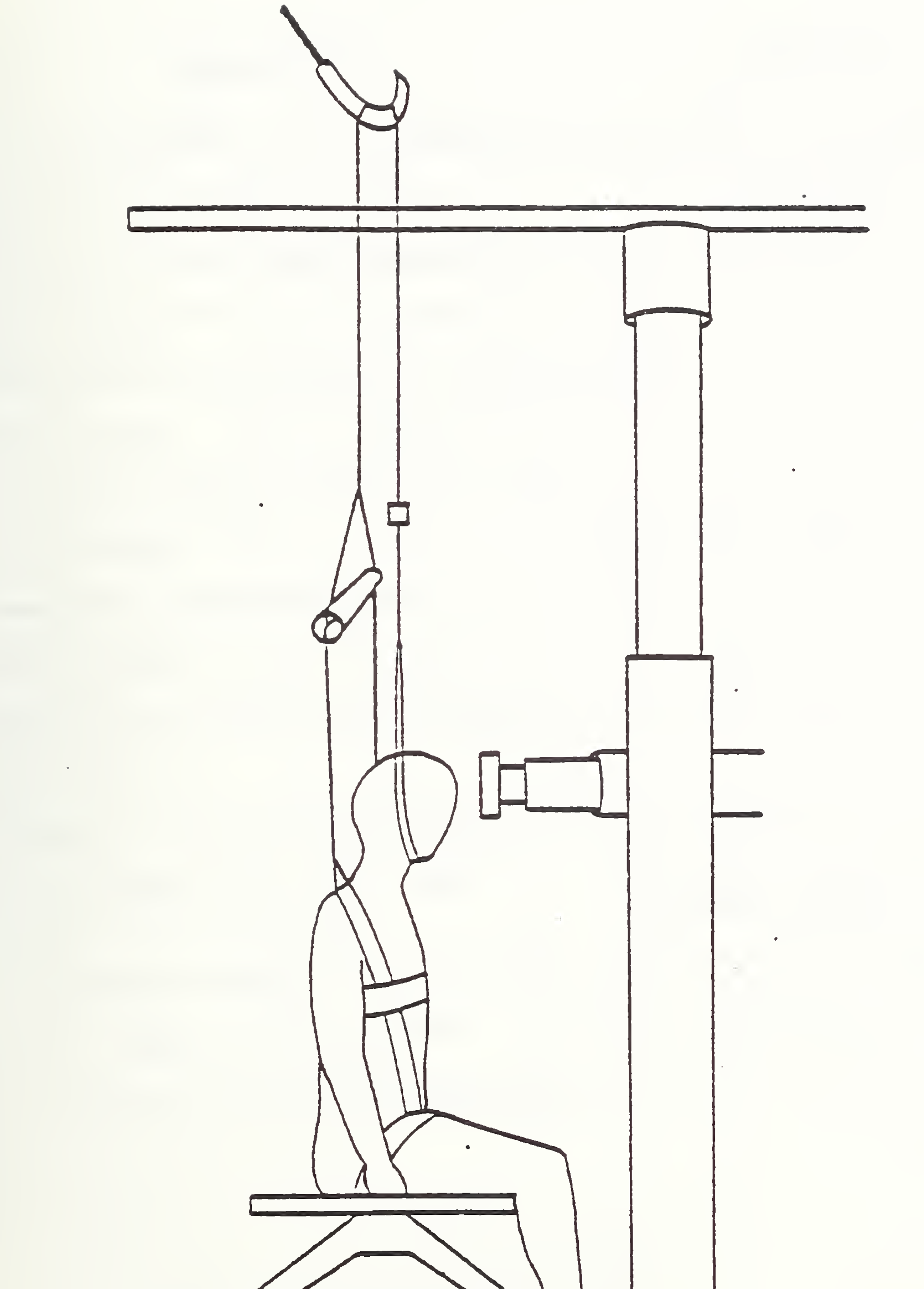
Pretest Trial Run

1. ___ Suspend rubber tube five inches from pendulum with fiber tape.
2. ___ Tape all accelerometers to seat with paper tape.
3. ___ Attach the contact switches to the load cell and shock absorber with paper tape.
4. ___ Run trial test.
5. ___ Record all signals, gate, and strobe.
6. ___ Put a one-volt signal on a junk tape and check to see if one volt is played back. Use signal generator or impedance-matching amp with the scope to calibrate output.

HEAD IMPACT 1

Test No.__________

TASK	TIME	COMMENTS
Head impact 1.		
Attach ball targets and phototargets.		
Change padding on impactor head surface.		
Set up head catch and spinal backup.		
Final positioning (see figure).		
Measure and record head and neck angles		
Setup photos.		
Final checklist.		
Start pressurization of vascular and cerebrospinal systems.		
Finish pressurizatons.		
Run test.		



HEAD IMPACT 1

Timer Box Setup

EQUIPMENT __________ Impact	TIMER VALUES Delay		Run
Gate (from strobe 1)	0011	1	0170
Lights (start)	0001	2	2600
HyCam (start)	1200	3	1600
Pendulum rope cutter(start)	1390	4	0050
Photosonics (start)	1000	5	1600
		6	
Head, pelvis, rope cutter (from velocity probe)	0001	7	0050
Piston Acceleration Corridor	0009	8	0050

FINAL CHECKLIST

____ check transducers

____ tape positioned

____ slots for velocity probe lined up

____ both strobes charged

____ timer box values correct

____ all timer box switches to 'off'

____ rope cutter threaded and ready

____ nylon (rope cutter) string unfrayed

____ rope cutter cable free

____ cameras set

____ Newtonian reference

____ calibration target

____ targets in view of cameras

____ padding

____ correct timers charged

____ gate trigger established

____ timing lights on

____ doors locked

____ final positioning

____ correct pressure system used

____ pendulum raised

____ power on

____ all pressure connections secured

____ zero piston accelerometer

____ head and neck angles

HEAD IMPACT 2

Test No.__________

TASK	TIME	COMMENTS
Reposition as for tap.		
Check spinal brace and head catch.		
Final positioning		
Measure and record head and neck angles		
Setup photos.		
Start pressurization of vascular and cerebrospinal systems.		
Final checklist.		
Finish pressurization.		
Run test.		

HEAD IMPACT 2

Timer Box Setup

EQUIPMENT ________ Impact	TIMER VALUES Delay		Run
Gate (from strobe 1)	0008	1	0170
Lights (start)	0001	2	2600
HyCam (start)	1200	3	1600
Pendulum rope cutter(start)	1290	4	0050
Photosonics (start)	1000	5	1600
		6	
Head, pelvis, rope cutter (from velocity probe)	0001	7	0050
Piston Acceleration Corridor	0009	8	0050

FINAL CHECKLIST

____ check transducers

____ tape positioned

____ slots for velocity probe lined up

____ both strobes charged

____ timer box values correct

____ all timer box switches to 'off'

____ rope cutter threaded and ready

____ nylon (rope cutter) string unfrayed

____ rope cutter cable free

____ cameras set

____ Newtonian reference

____ calibration target

____ targets in view of cameras

____ padding

____ correct timers charged

____ gate trigger established

____ timing lights on

____ doors locked

____ final positioning

____ correct pressure system used

____ pendulum raised

____ power on

____ all pressure connections secured

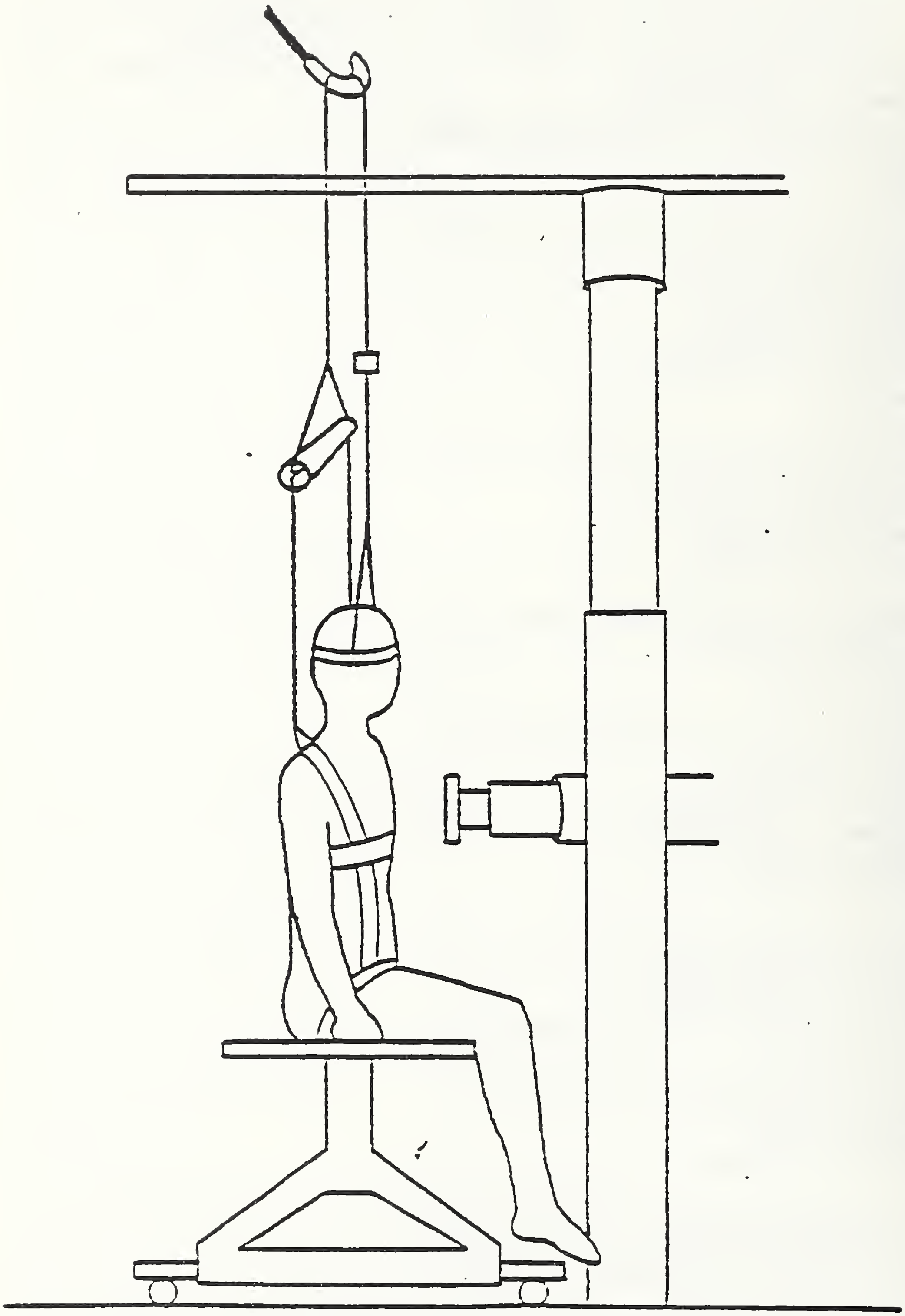
____ zero piston accelerometer

____ head and neck angles

THORAX FRONT TAP

Test No.__________

TASK	TIME	COMMENTS
Place seat in position and square on pendulum.		
String up rope cutters.		
Position subject as per figure with body and head harnesses. Protect any mounts that may be hit with gauze and padding.		
Subject should be in normal sitting position with back inclined approx. 10° forwards.		
Attach ball targets and phototargets.		
Place one of the pressure transducers that was in the head in the trachea, and place the Kulite in the descending aorta.		
Final positioning and setup photos (see fig)		
Final checklist.		
Start pressurization of vascular and respiratory systems.		
Finish pressurization.		
Run test.		



THORAX FRONT TAP

Timer Box Setup

EQUIPMENT	TIMER VALUES		
__________ Impact	Delay		Run
Gate (from strobe 1)	0021	1	0170
Lights (start)	0001	2	2600
HyCam (start)	1200	3	1600
Pendulum rope cutter(start)	1400	4	0050
Photosonics (start)	1000	5	1600
		6	
Head, pelvis, rope cutter (from velocity probe)	0001	7	0050
Piston Acceleration Corridor	0012	8	0150

FINAL CHECKLIST

____ check transducers

____ tape positioned

____ slots for velocity probe lined up

____ both strobes charged

____ timer box values correct

____ all timer box switches to 'off'

____ rope cutter threaded and ready

____ nylon (rope cutter) string unfrayed

____ rope cutter cable free

____ cameras set

____ Newtonian reference

____ calibration target

____ targets in view of cameras

____ padding

____ correct timers charged

____ gate trigger established

____ timing lights on

____ doors locked

____ final positioning

____ correct pressure system used

____ pendulum raised

____ power on

____ all pressure connections secured

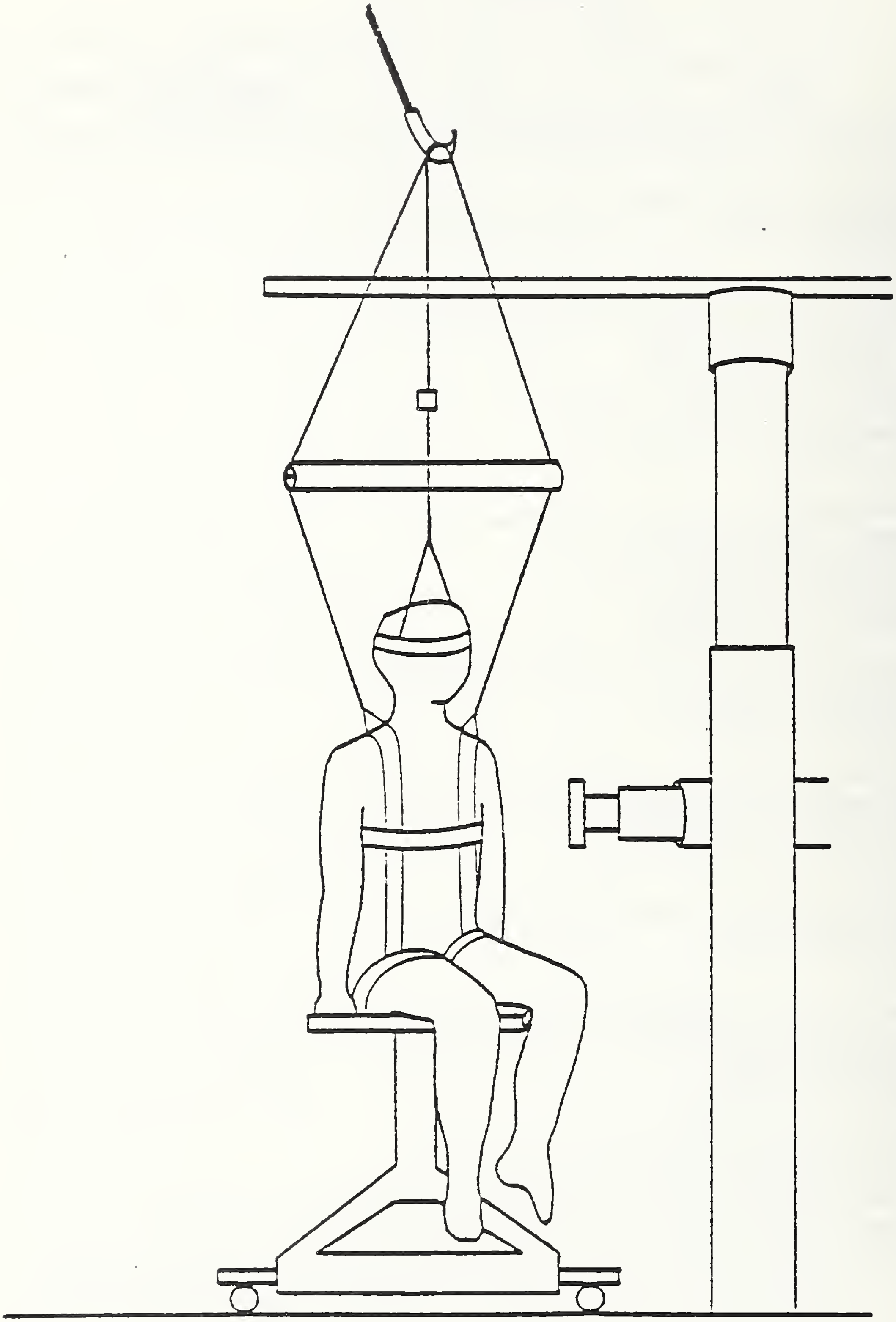
____ zero piston accelerometer

____ head and neck angles

45° THORAX TAP

Test No.__________

TASK	TIME	COMMENTS
Place seat in position.		
String up rope cutters.		
Position subject as per figure with body and head harnesses. Protect any mounts that may be hit with gauze and padding.		
Subject should be in normal sitting position with back inclined approx. 10° forwards.		
Attach ball targets and phototargets.		
Final positioning and setup photos (see fig)		
Final checklist.		
Start pressurization of vascular and respiratory systems.		
Finish pressurization.		
Run test.		



45° THORAX TAP

Timer Box Setup

EQUIPMENT __________ Impact	TIMER VALUES Delay		Run
Gate (from strobe 1)	0021	1	0170
Lights (start)	0001	2	2600
HyCam (start)	1200	3	1600
Pendulum rope cutter(start)	1400	4	0050
Photosonics (start)	1000	5	1600
.		6	
Head, pelvis, rope cutter (from velocity probe)	0001	7	0050
Piston Acceleration Corridor	0012	8	0150

FINAL CHECKLIST

____ check transducers

____ tape positioned

____ slots for velocity probe lined up

____ both strobes charged

____ timer box values correct

____ all timer box switches to 'off'

____ rope cutter threaded and ready

____ nylon (rope cutter) string unfrayed

____ rope cutter cable free

____ cameras set

____ Newtonian reference

____ calibration target

____ targets in view of cameras

____ padding

____ correct timers charged

____ gate trigger established

____ timing lights on

____ doors locked

____ final positioning

____ correct pressure system used

____ pendulum raised

____ power on

____ all pressure connections secured

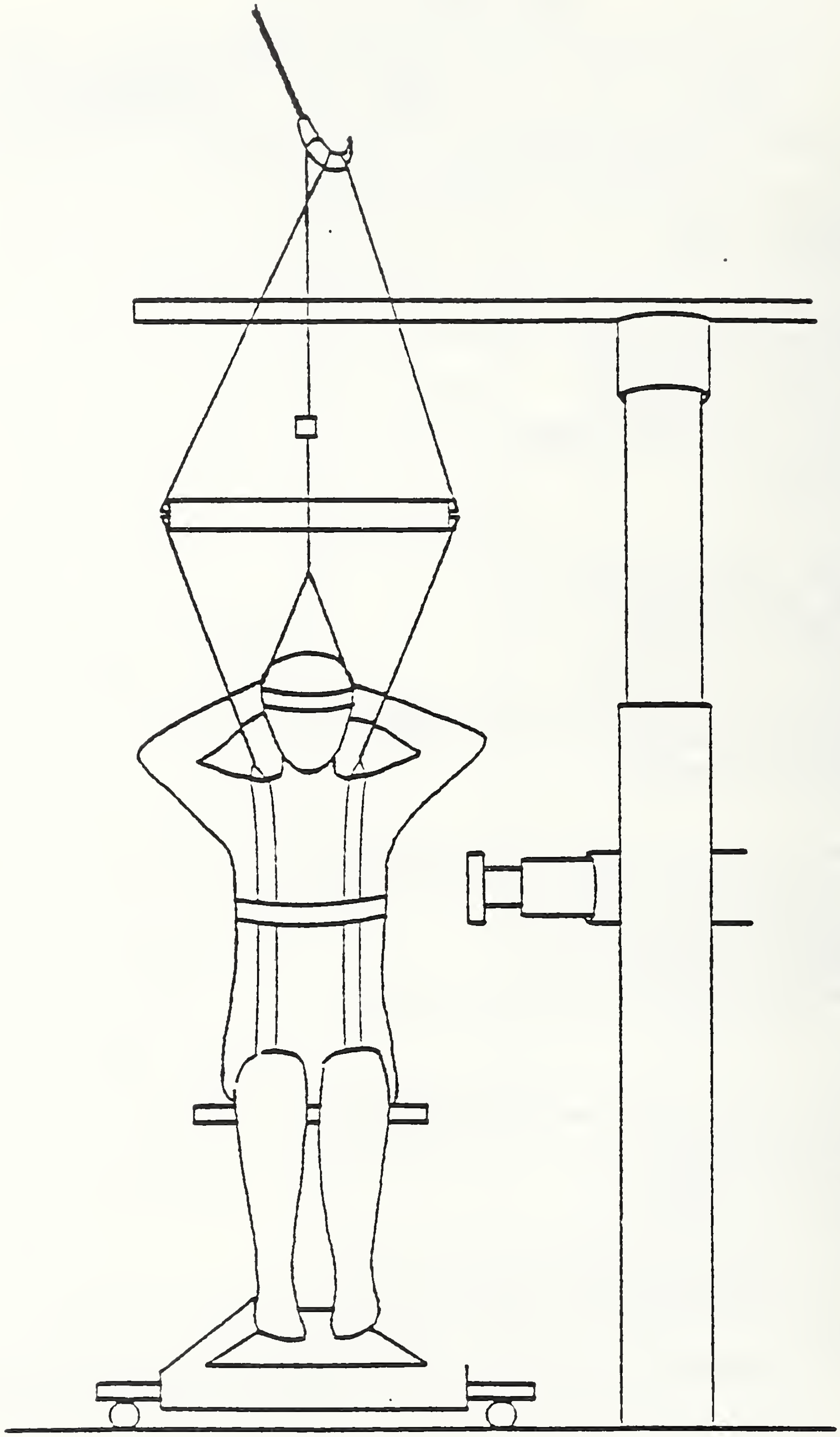
____ zero piston accelerometer

____ head and neck angles

OPTIONAL ARMS-UP THORAX TAP

Test No.__________

TASK	TIME	COMMENTS
Place seat in position.		
String up rope cutters.		
Position subject as per figure with body and head harnesses. Protect any mounts that may be hit with gauze and padding.		
Subject should be in normal sitting position with back inclined approx. 10° forwards.		
Attach ball targets and phototargets.		
Final positioning and setup photos see drawings and figures by ***PAULA LUX***		
Final checklist.		
Start pressurization of vascular and respiratory systems.		
Finish pressurization.		
Run test.		



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OPTIONAL ARMS-UP THORAX TAP

Timer Box Setup

EQUIPMENT	TIMER VALUES		
Impact	Delay		Run
Gate (from strobe 1)	0021	1	0170
Lights (start)	0001	2	2600
HyCam (start)	1200	3	1600
Pendulum rope cutter(start)	1400	4	0050
Photosonics (start)	1000	5	1600
		6	
Head, pelvis, rope cutter (from velocity probe)	0001	7	0050
Piston Acceleration Corridor	0012	8	0150

FINAL CHECKLIST

____ check transducers

____ tape positioned

____ slots for velocity probe lined up

____ both strobes charged

____ timer box values correct

____ all timer box switches to 'off'

____ rope cutter threaded and ready

____ nylon (rope cutter) string unfrayed

____ rope cutter cable free

____ cameras set

____ Newtonian reference

____ calibration target

____ targets in view of cameras

____ padding

____ correct timers charged

____ gate trigger established

____ timing lights on

____ doors locked

____ final positioning

____ correct pressure system used

____ pendulum raised

____ power on

____ all pressure connections secured

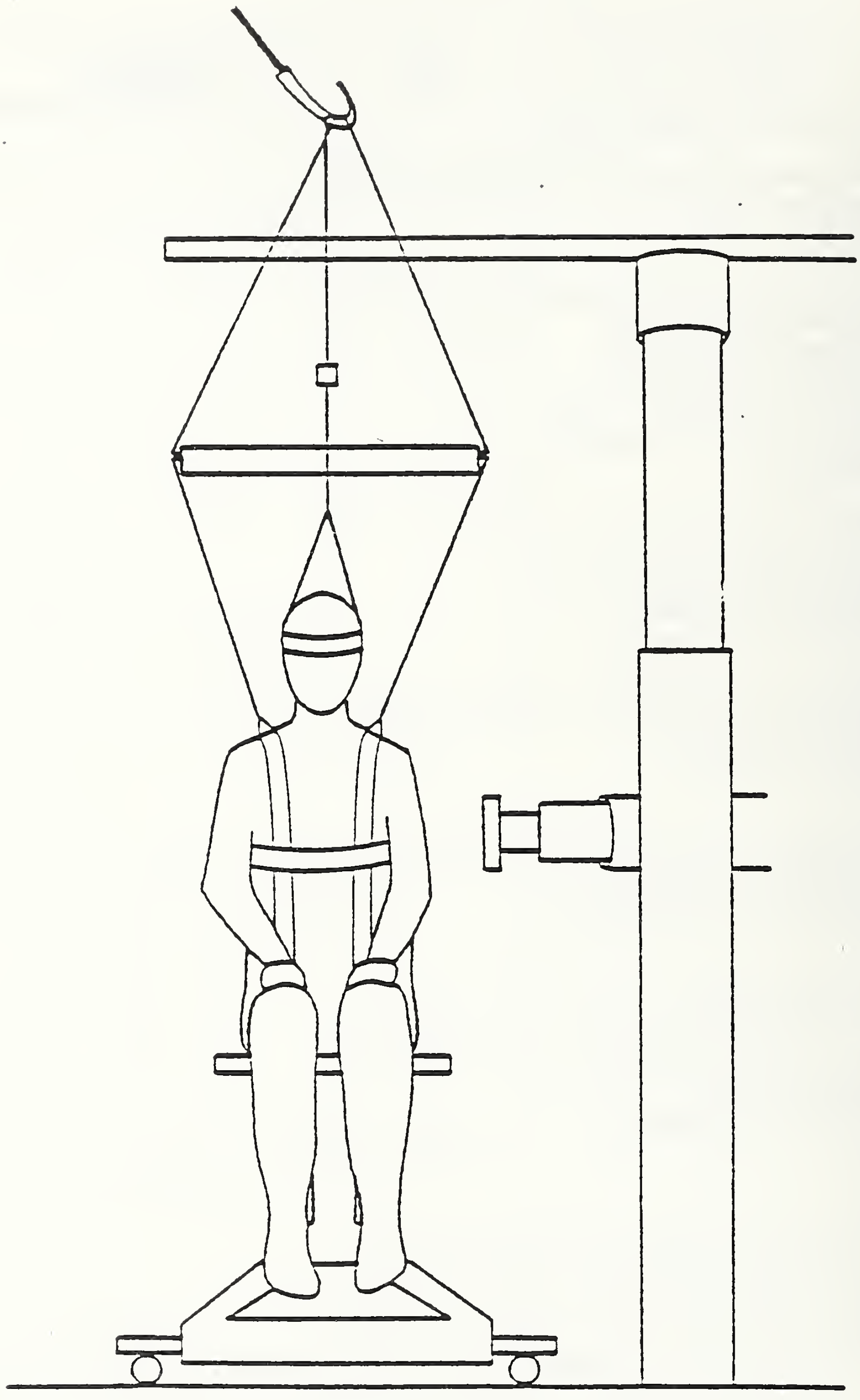
____ zero piston accelerometer

____ head and neck angles

ARMS-DOWN THORAX TAP

Test No.__________

TASK	TIME	COMMENTS
Place seat in position.		
String up rope cutters.		
Position subject as per figure with body and head harnesses. Protect any mounts that may be hit with gauze and padding.		
Subject should be in normal sitting position with back inclined approx. 10° forwards.		
Attach ball targets and phototargets.		
Final positioning and setup photos (see fig)		
Final checklist.		
Start pressurization of vascular and respiratory systems.		
Finish pressurization.		
Run test.		



Thorax taps - 60

ARMS-DOWN THORAX TAP

Timer Box Setup

EQUIPMENT Impact	TIMER VALUES Delay		Run
Gate (from strobe 1)	0021	1	0170
Lights (start)	0001	2	2600
HyCam (start)	1200	3	1600
Pendulum rope cutter(start)	1400	4	0050
Photosonics (start)	1000	5	1600
		6	
Head, pelvis, rope cutter (from velocity probe)	0001	7	0050
Piston Acceleration Corridor	0012	8	0150

FINAL CHECKLIST

____ check transducers

____ tape positioned

____ slots for velocity probe lined up

____ both strobes charged

____ timer box values correct

____ all timer box switches to 'off'

____ rope cutter threaded and ready

____ nylon (rope cutter) string unfrayed

____ rope cutter cable free

____ cameras set

____ Newtonian reference

____ calibration target

____ targets in view of cameras

____ padding

____ correct timers charged

____ gate trigger established

____ timing lights on

____ doors locked

____ final positioning

____ correct pressure system used

____ pendulum raised

____ power on

____ all pressure connections secured

____ zero piston accelerometer

____ head and neck angles

THORAX IMPACT

Test No.__________

TASK	TIME	COMMENTS
Reposition for shoulder (arms down) impact.		
Set up catch net.		
Slacken body harness.		
Start pressurization of vascular and respiratory systems.		
Final checklist.		
Finish pressurization.		
Run test		

ARMS-DOWN THORAX IMPACT

Timer Box Setup

EQUIPMENT	TIMER VALUES		
____________ Impact	Delay		Run
Gate (from strobe 1)	0006	1	0170
Lights (start)	0001	2	2600
HyCam (start)	1200	3	1600
Pendulum rope cutter(start)	1220	4	0050
Photosonics (start)	1000	5	1600
		6	
Head, pelvis, rope cutter (from velocity probe)	0002	7	0050
Piston Acceleration Corridor	0006	8	0050

FINAL CHECKLIST

____ check transducers

____ tape positioned

____ slots for velocity probe lined up

____ both strobes charged

____ timer box values correct

____ all timer box switches to 'off'

____ rope cutter threaded and ready

____ nylon (rope cutter) string unfrayed

____ rope cutter cable free

____ cameras set

____ Newtonian reference

____ calibration target

____ targets in view of cameras

____ padding

____ correct timers charged

____ gate trigger established

____ timing lights on

____ doors locked

____ final positioning

____ correct pressure system used

____ pendulum raised

____ power on

____ all pressure connections secured

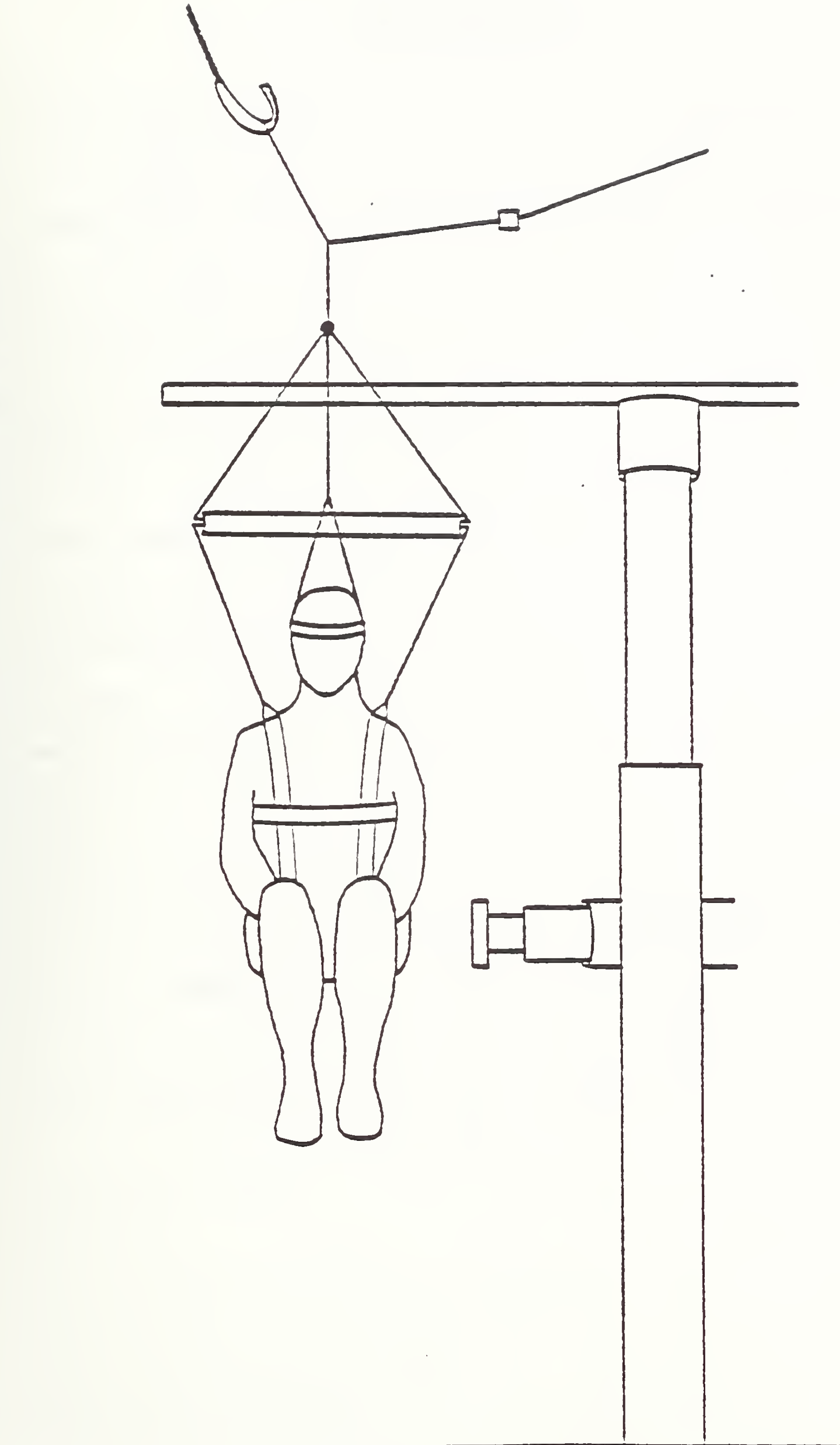
____ zero piston accelerometer

____ head and neck angles

PELVIS IMPACT

Test No.__________

TASK	TIME	COMMENTS
Install pelvic and spinal accelerometers. Stuff and sew. Pad pelvic plate.		
Attach ball targets and phototargets.		
Change padding on impact head surface.		
Final positioning, setup photos (see fig)		
Final checklist.		
Run test.		



PELVIS IMPACT

Timer Box Setup

EQUIPMENT	TIMER VALUES		
___________ Impact	Delay		Run
Gate (from strobe 1)	0006	1	0170
Lights (start)	0001	2	2600
HyCam (start)	1200	3	1600
Pendulum rope cutter(start)	1220	4	0050
Photosonics (start)	1000	5	1600
		6	
Head, pelvis, rope cutter (from velocity probe)	0002	7	0050
Piston Acceleration Corridor	0006	8	0050

FINAL CHECKLIST

____ check transducers

____ tape positioned

____ slots for velocity probe lined up

____ both strobes charged

____ timer box values correct

____ all timer box switches to 'off'

____ rope cutter threaded and ready

____ nylon (rope cutter) string unfrayed

____ rope cutter cable free

____ cameras set

____ Newtonian reference

____ calibration target

____ targets in view of cameras

____ padding

____ correct timers charged

____ gate trigger established

____ timing lights on

____ doors locked

____ final positioning

____ correct pressure system used

____ pendulum raised

____ power on

____ all pressure connections secured

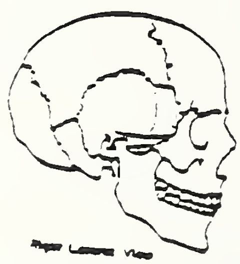
____ zero piston accelerometer

____ head and neck angles

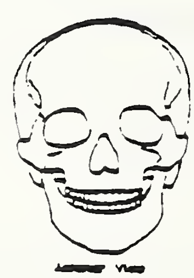
POST TEST PROCEDURE

TASK	TIME	COMMENTS
Remove all targets and triax clusters.		
Store cadaver if necessary.		
Transport cadaver to anatomy lab.		
Remove all instrumentation, except for 9AX head plate.		
Remove head and transport it to X-Ray Room for post test radiographs.		

Z-X
(Profile)



Z-Y
(Frontal)



X-RAYS (X-RAY ROOM)

Reference Point	Z-X Distance from Table	Z-Y Distance from Table
R. Eye		
L. Eye		
R. Ear		
L. Ear		
Q1		
Q2		
Q3		
CG		

	KVP	MA	SEC	LABEL	
Z-X					(100/10/1)
Z-Y					(100/10/1)

AUTOPSY

TASK	TIME	COMMENTS
After completion of radiographs, transport head to Anatomy Room for commencement of Autopsy.		
Autopsy		
SAVE RIBS RIGHT SIDE 4, 5, 6		

B76

Observed Injuries

1. Head: a. Brain b. Kull

2. Neck:

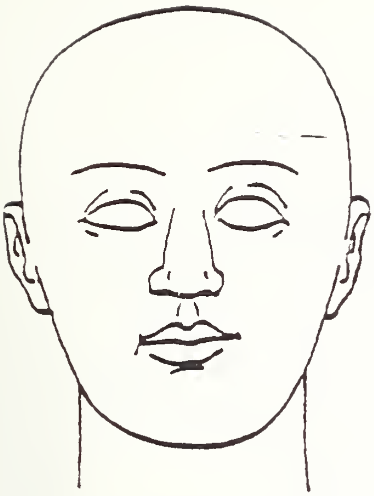
3. Thorax: a. Ribs b. Heart c. Lungs d. Diaphragm

4. Pelvis:

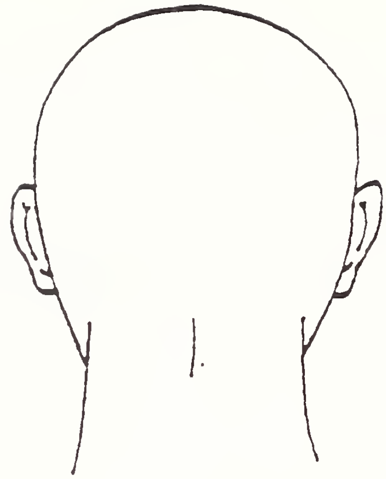
5. Femur

6. Abdomen

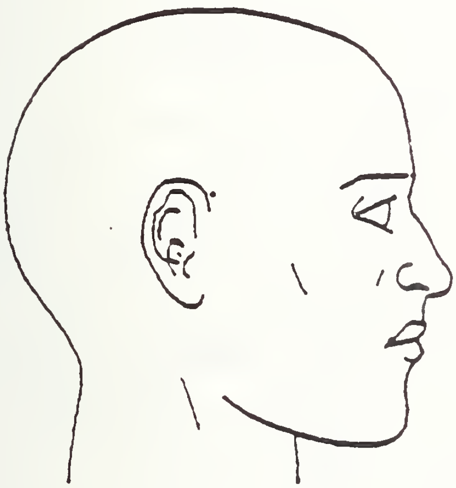
COMMENTS:



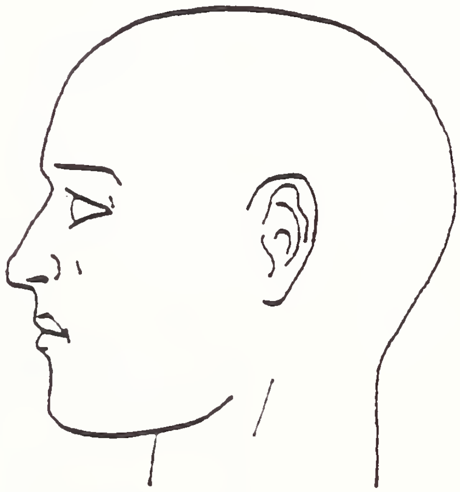
Anterior View



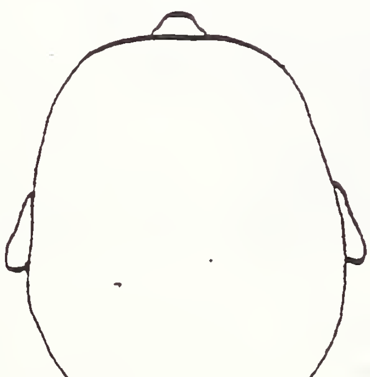
Posterior View



Right Lateral View

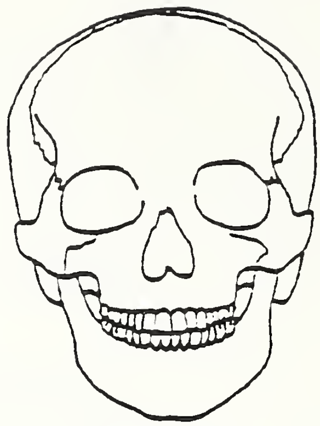


Left Lateral View

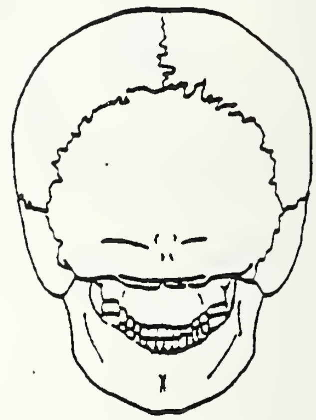


Superior View

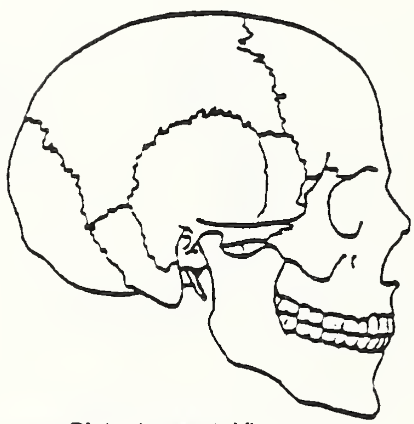
TEST NO. ____________



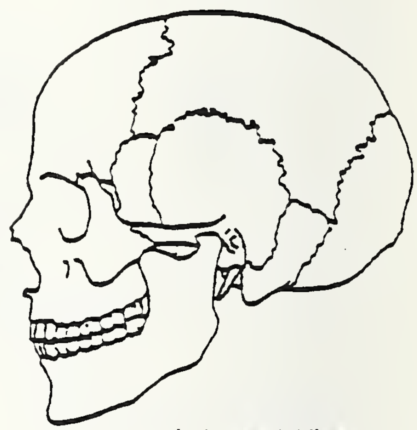
Anterior View



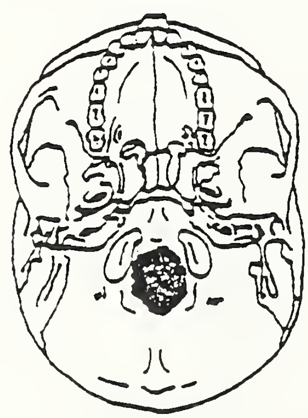
Posterior View



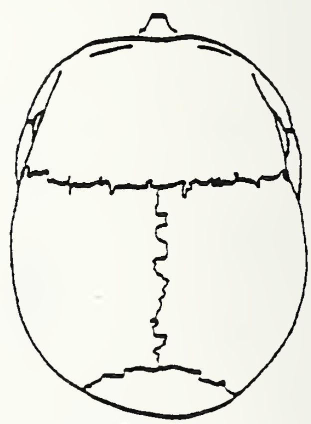
Right Lateral View



Left Lateral View



Inferior View



Superior View

TEST NO. ______________

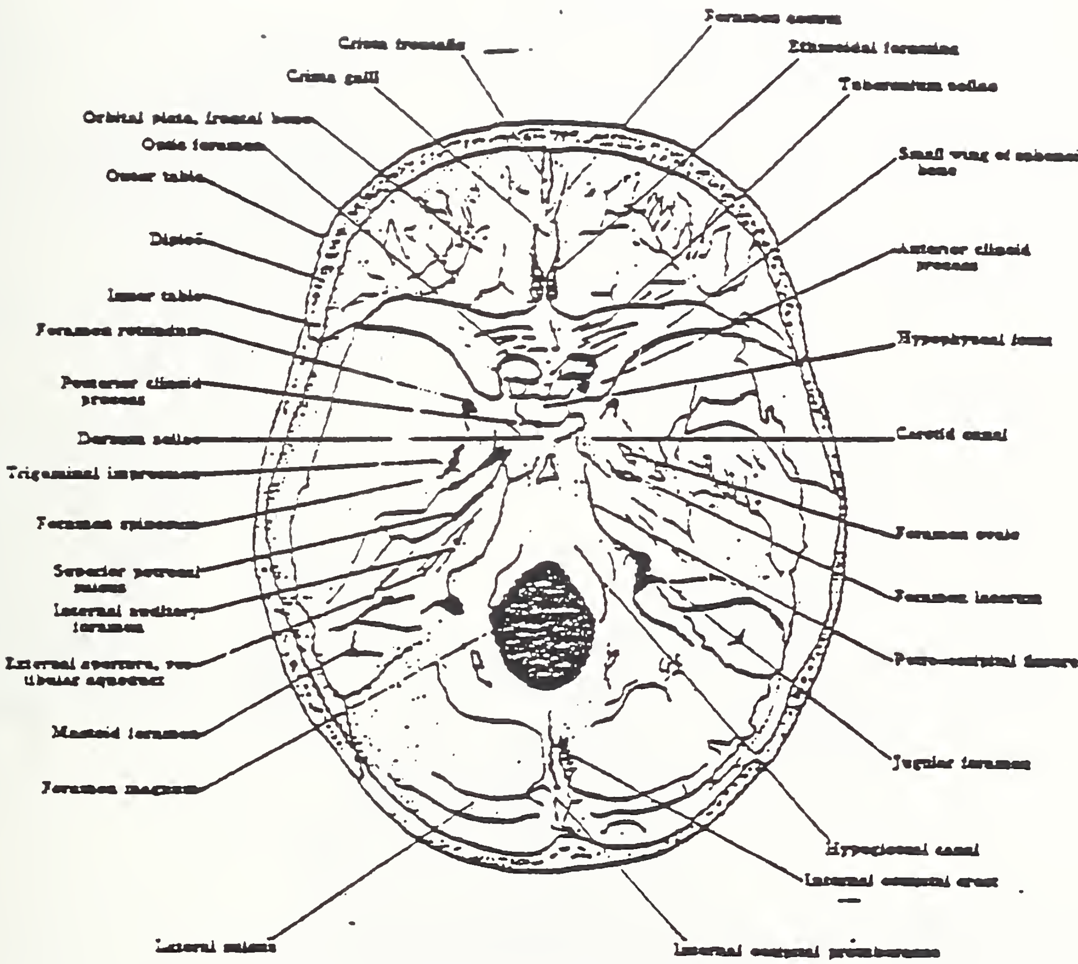
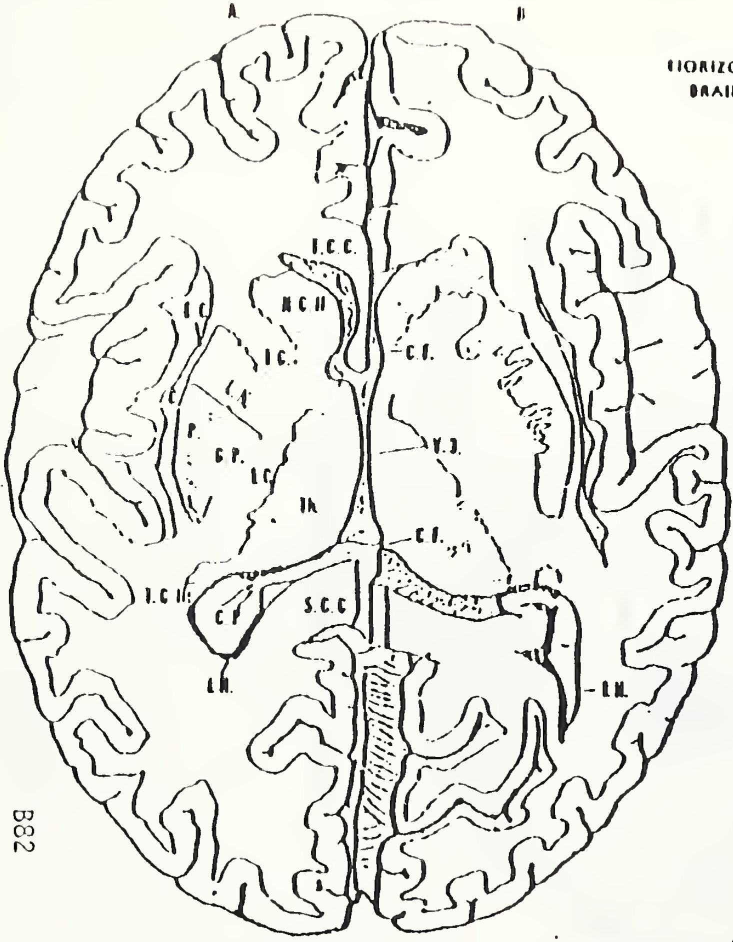
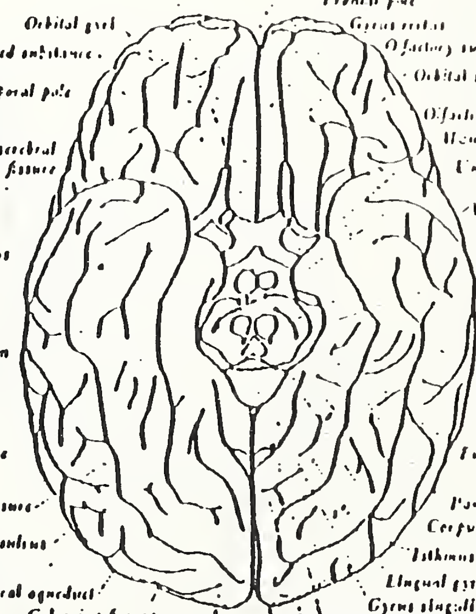


Fig. 109.—The Skull, Internal Aspect of the Base.

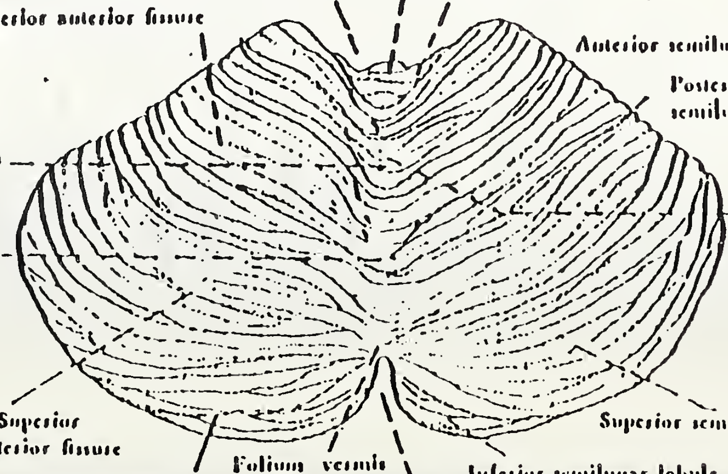


HORIZONTAL SECTIONS OF
BRAIN AT TWO LEVELS

C. — Claustrum
C.F. — Crus of Fornix
C.P. — Choroid Plexus
E.C. — External Capsule
G.P. — Globus Pallidus
H.C.N. — Head of Caudate Nucleus
I.C. — Internal Capsule
I.H. — Inferior Horn of Lateral Ventricle
L.N. — Lenticular Nucleus
P. — Putamen
S.C.C. — Splenium of Corpus Callosum
T.C.C. — Trunk of Corpus Callosum
T.C.N. — Tail of Caudate Nucleus
Th. — Thalamus
V.3. — 3rd Ventricle



Basal aspect of the human cerebral hemisphere. (Sobotta-McMurrich)



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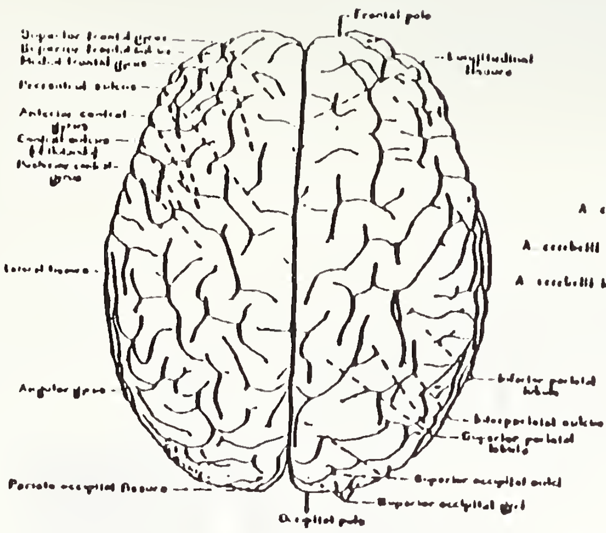
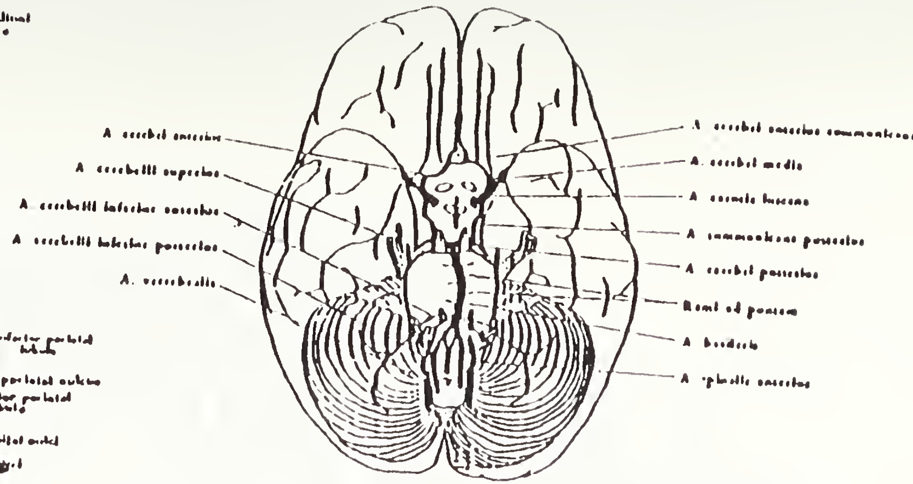
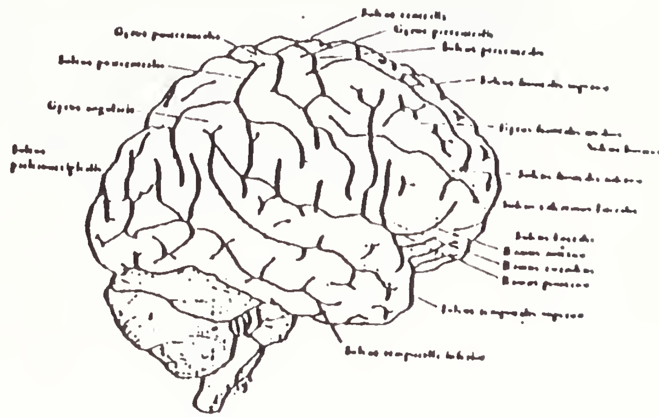


– Cerebral Hemispheres Viewed from Above.





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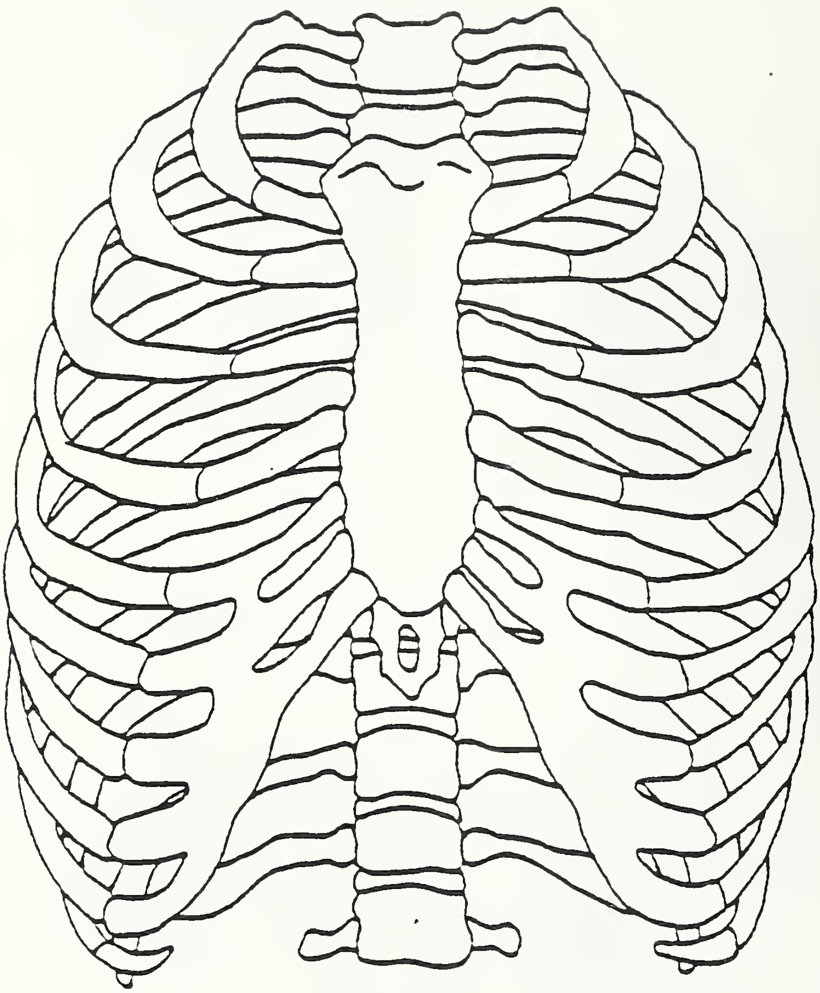
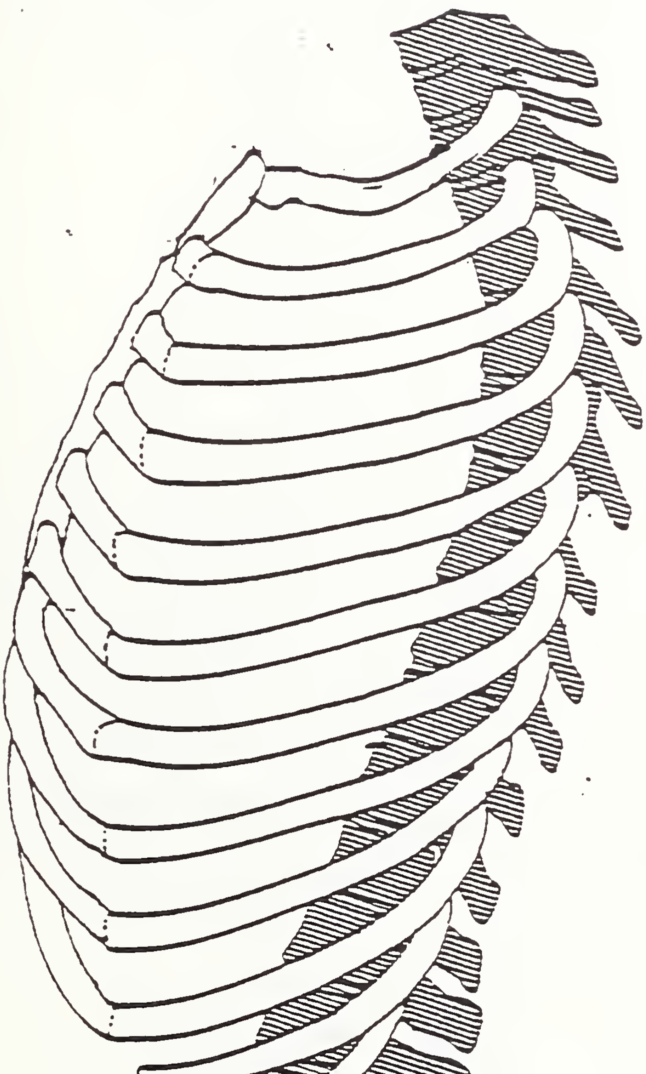


ANTERIOR THORAX

Test No.___________



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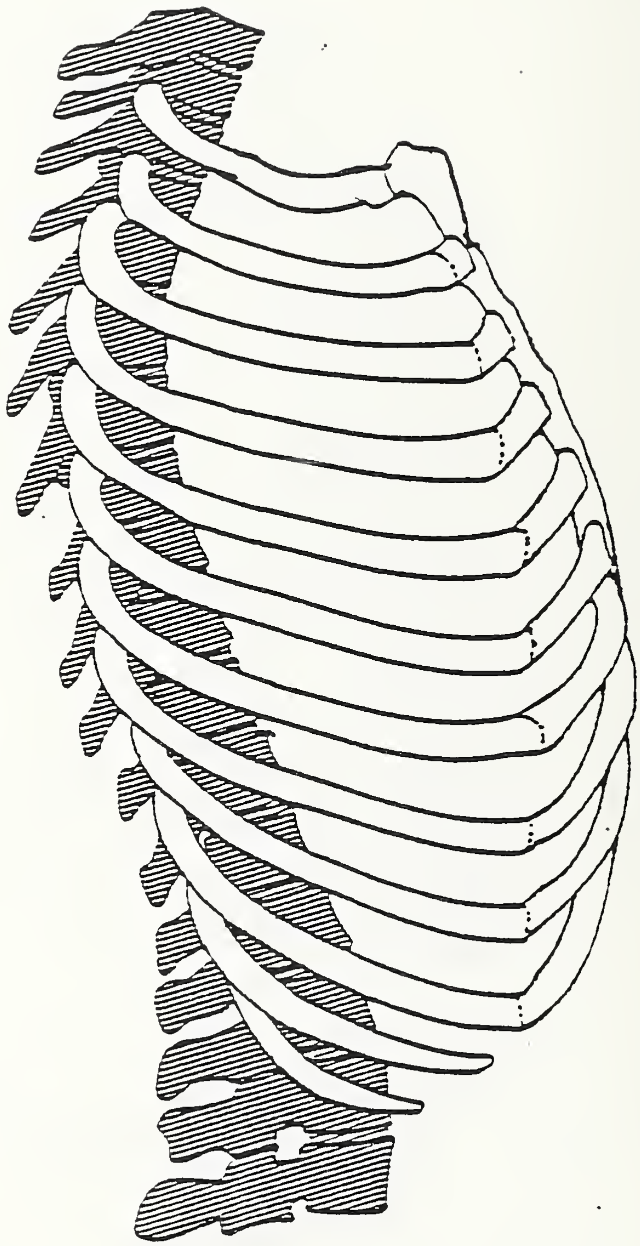
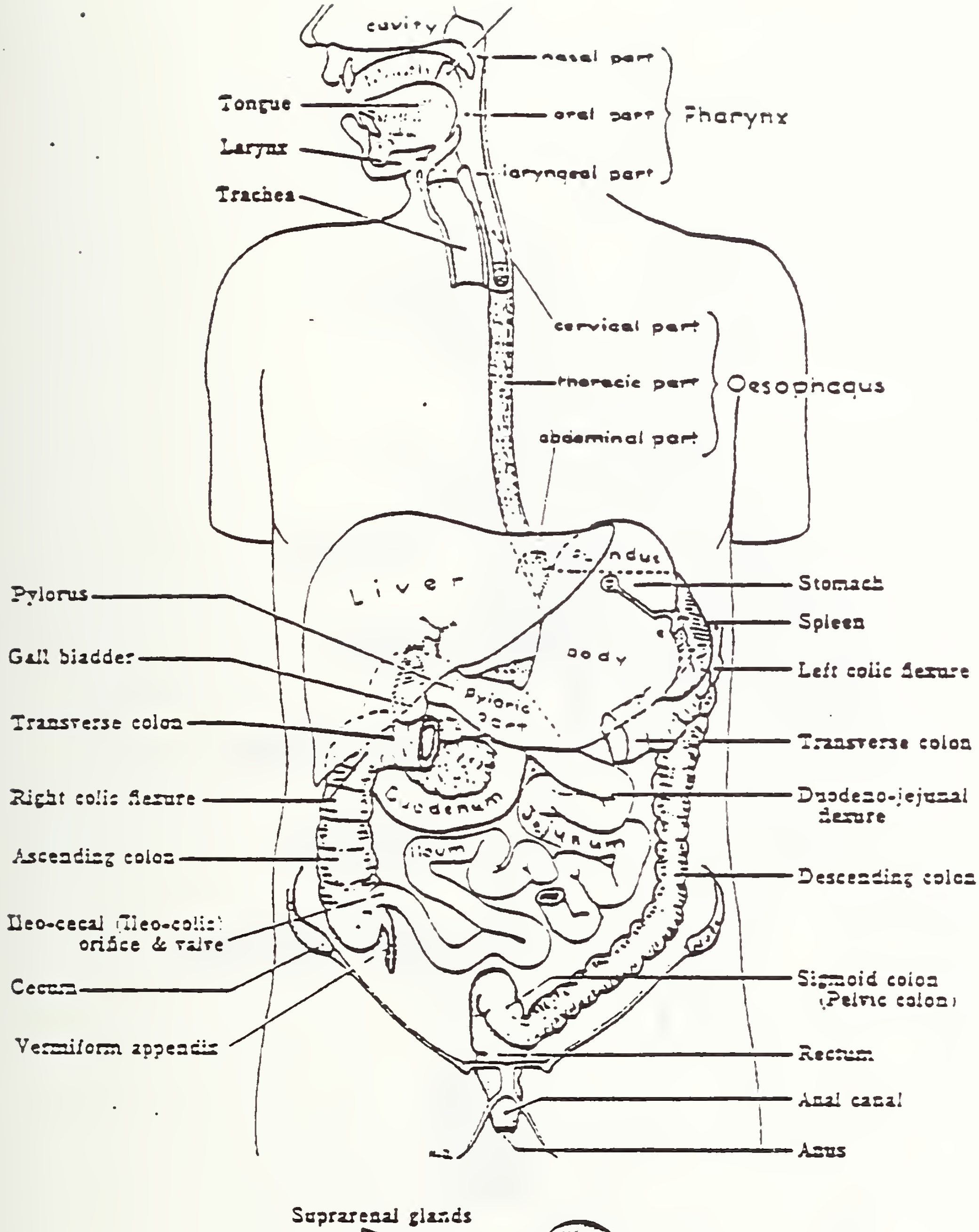
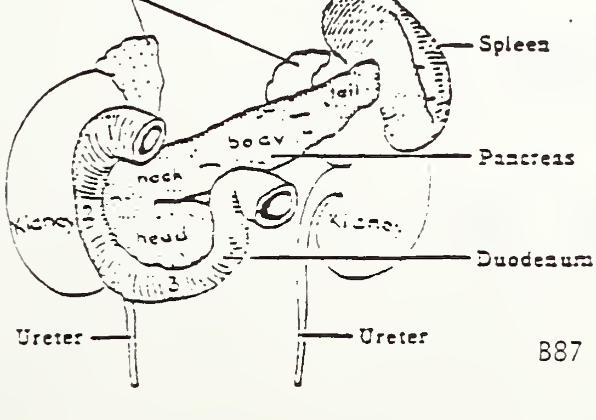


TEST NO. ________________

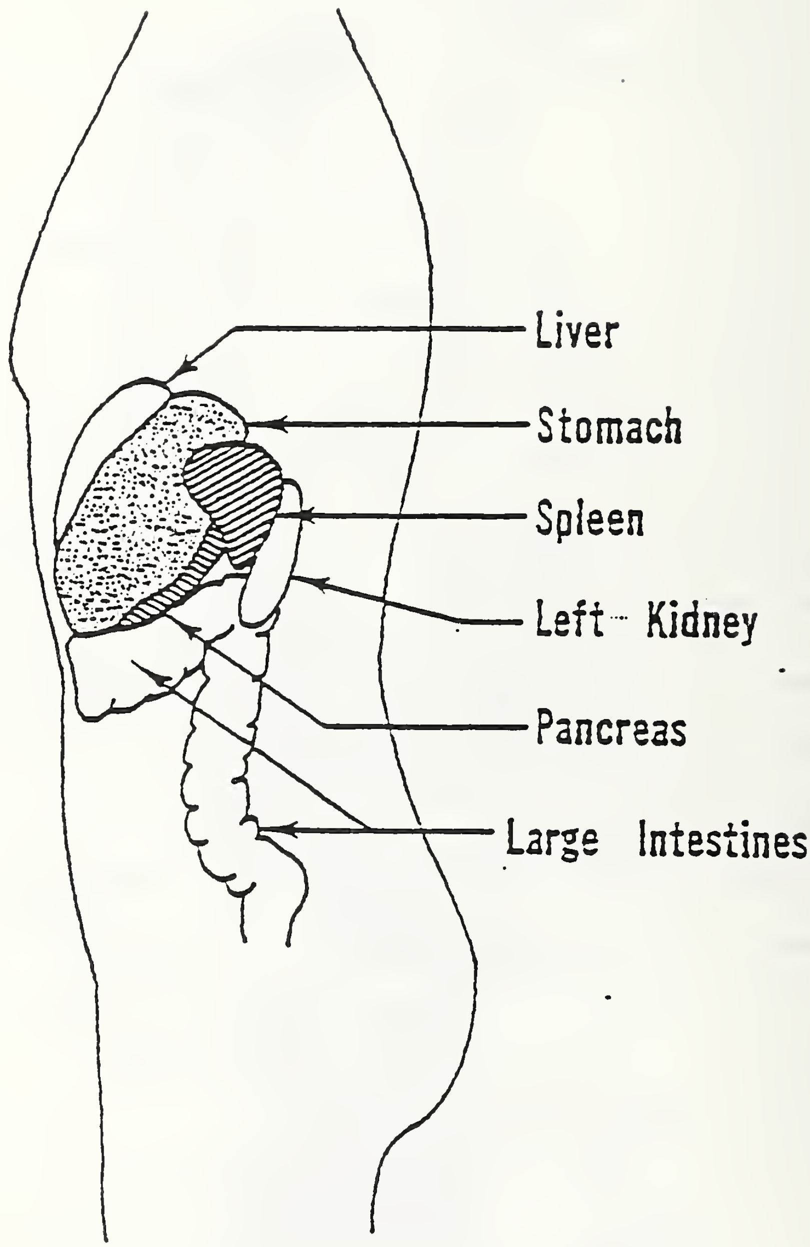


cavity
nasal part
Tongue
oral part
Pharynx
Larynx
laryngeal part
Trachea
cervical part
thoracic part
Oesophagus
abdominal part
Liver
fundus
Stomach
Pylorus
Spleen
body
Gall bladder
Left colic flexure
Pyloric part
Transverse colon
Transverse colon
Right colic flexure
Duodenum
Duodeno-jejunal flexure
Jejunum
Ascending colon
Ileum
Descending colon
Ileo-cecal (Ileo-colic) orifice & valve
Cecum
Sigmoid colon (Pelvic colon)
Vermiform appendix
Rectum
Anal canal
Anus



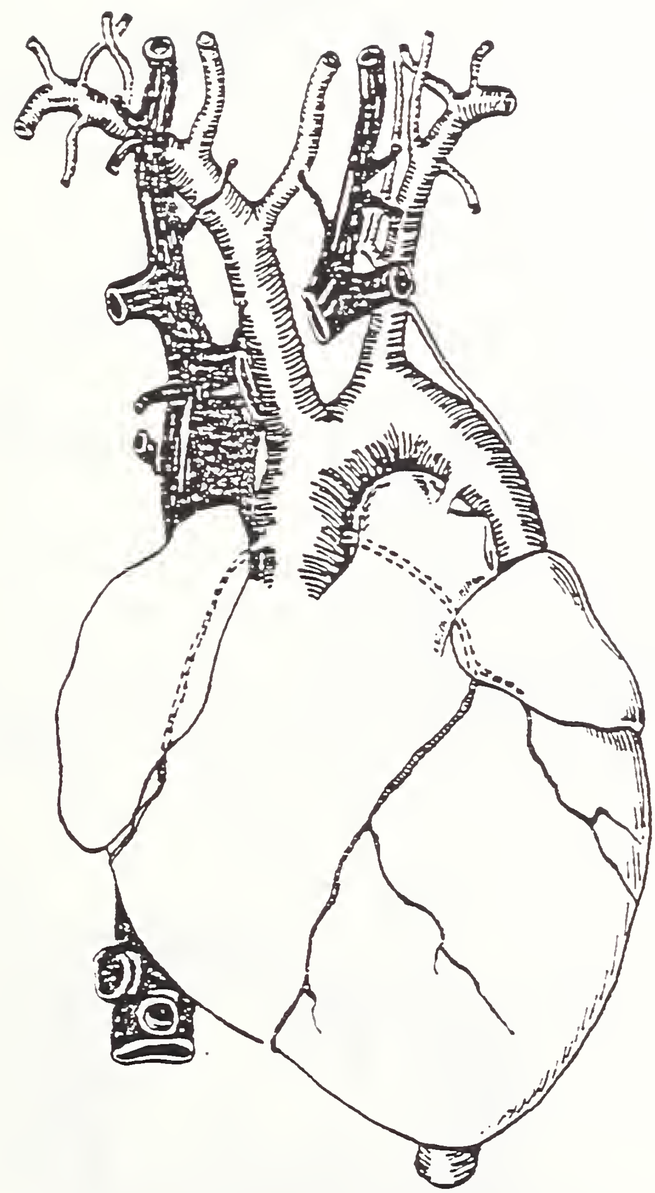
Suprarenal glands
Spleen
tail
body
Pancreas
neck
Kidney
head
Kidney
Duodenum
Ureter
Ureter

Test No.__________

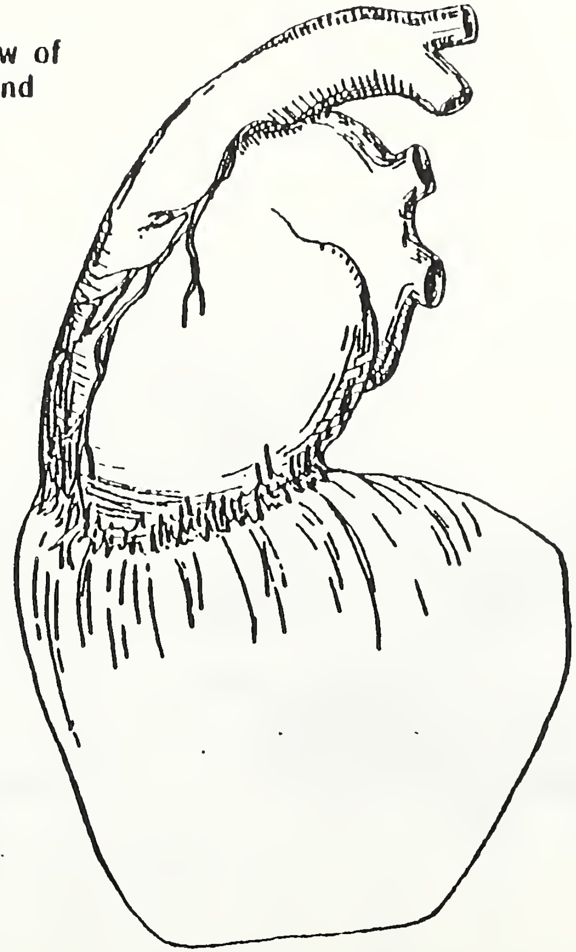


LEFT SIDE

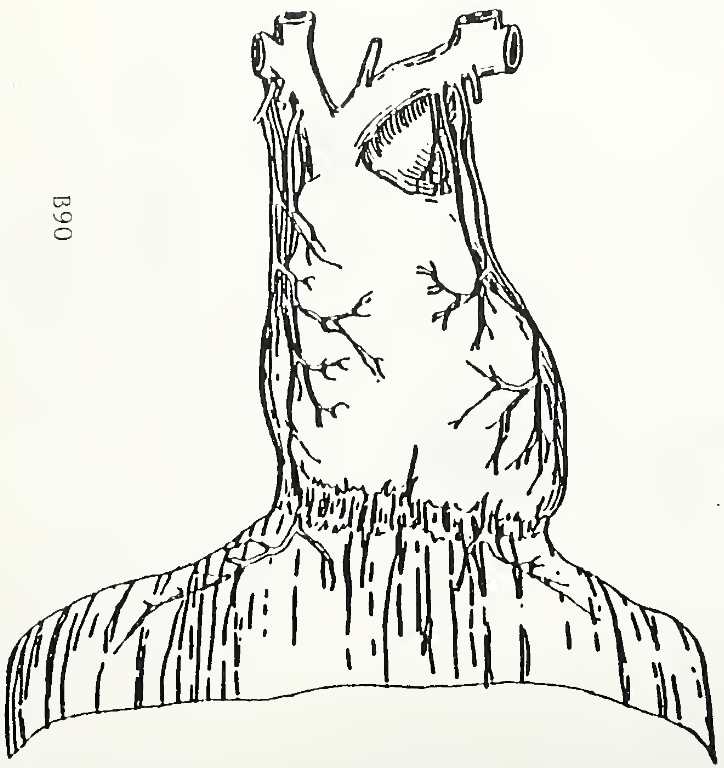
TEST NO. ____________



TEST NO. ____________

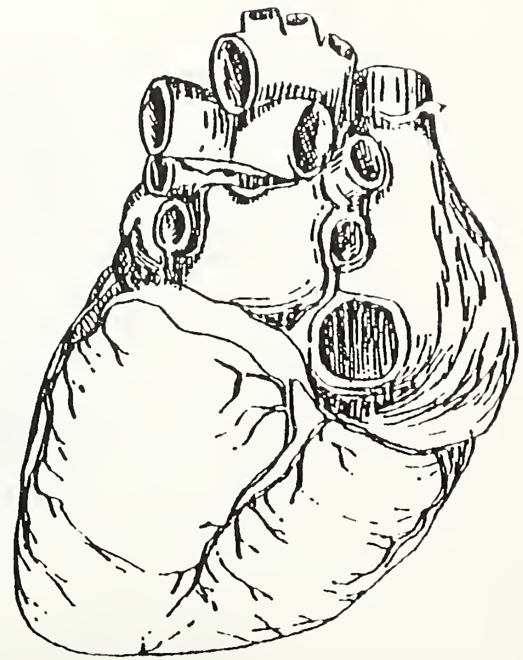


Left Side View of Pericardium and Diaphragm



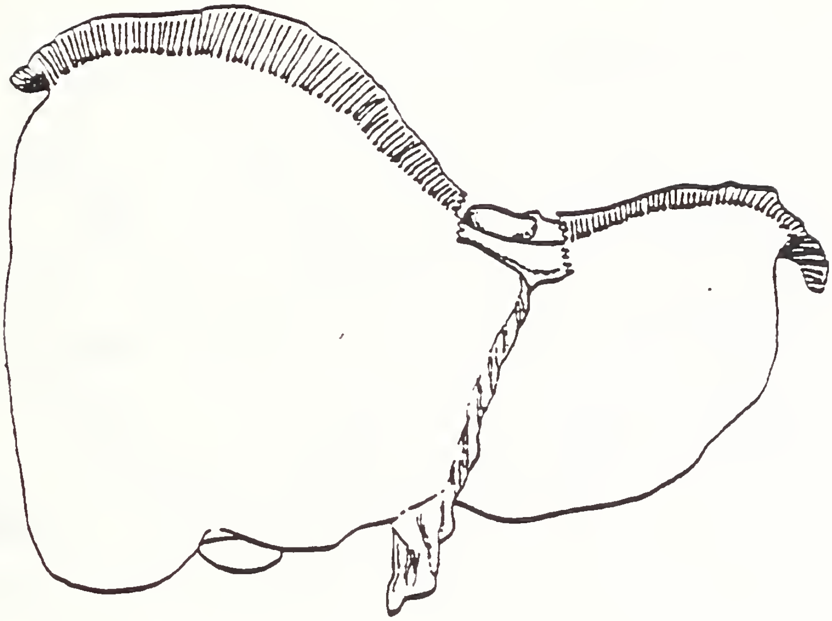
Anterior View of Pericardium and Diaphragm

Diaphragmatic View of Heart



LIVER IMPACT AUTOPSY SUMMARY

NO. ______________



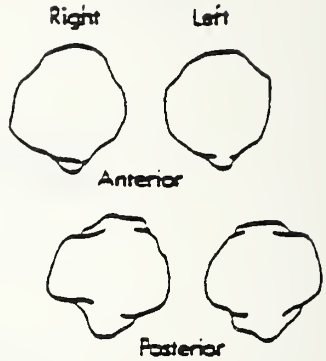
SUPERIOR SURFACE OF THE LIVER

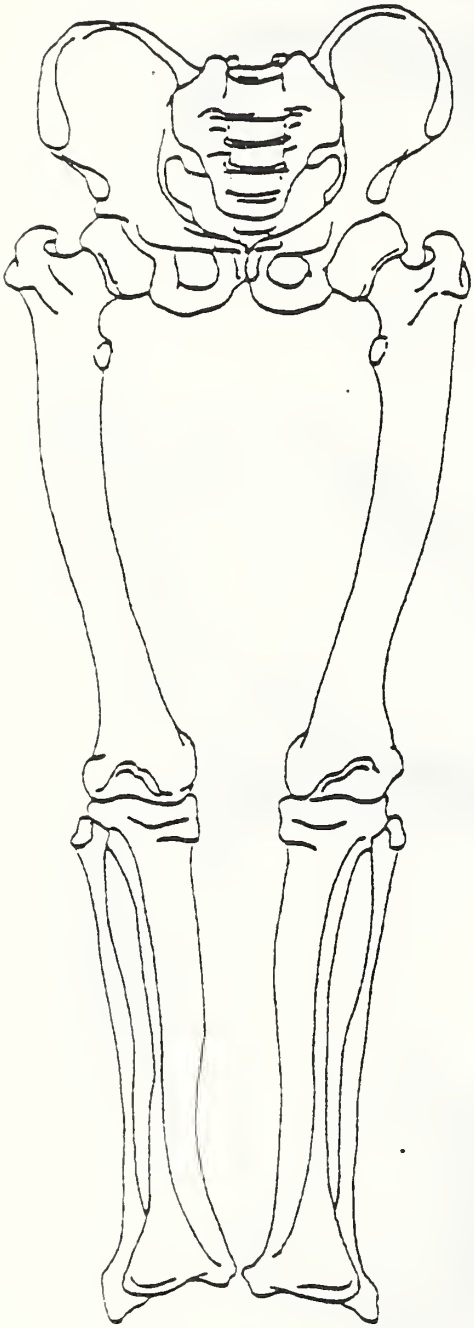
VISCERAL SURFACE OF THE LIVER

TEST NO. ____________________

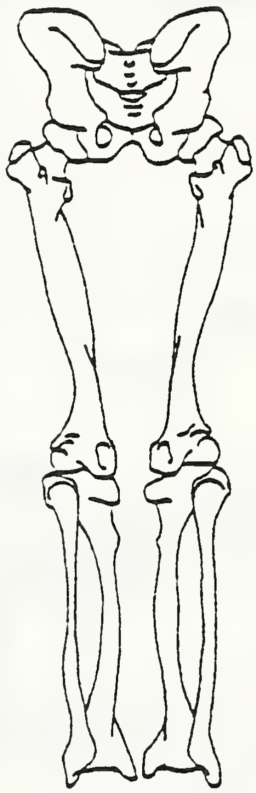
DATE ________________________

PATELLA





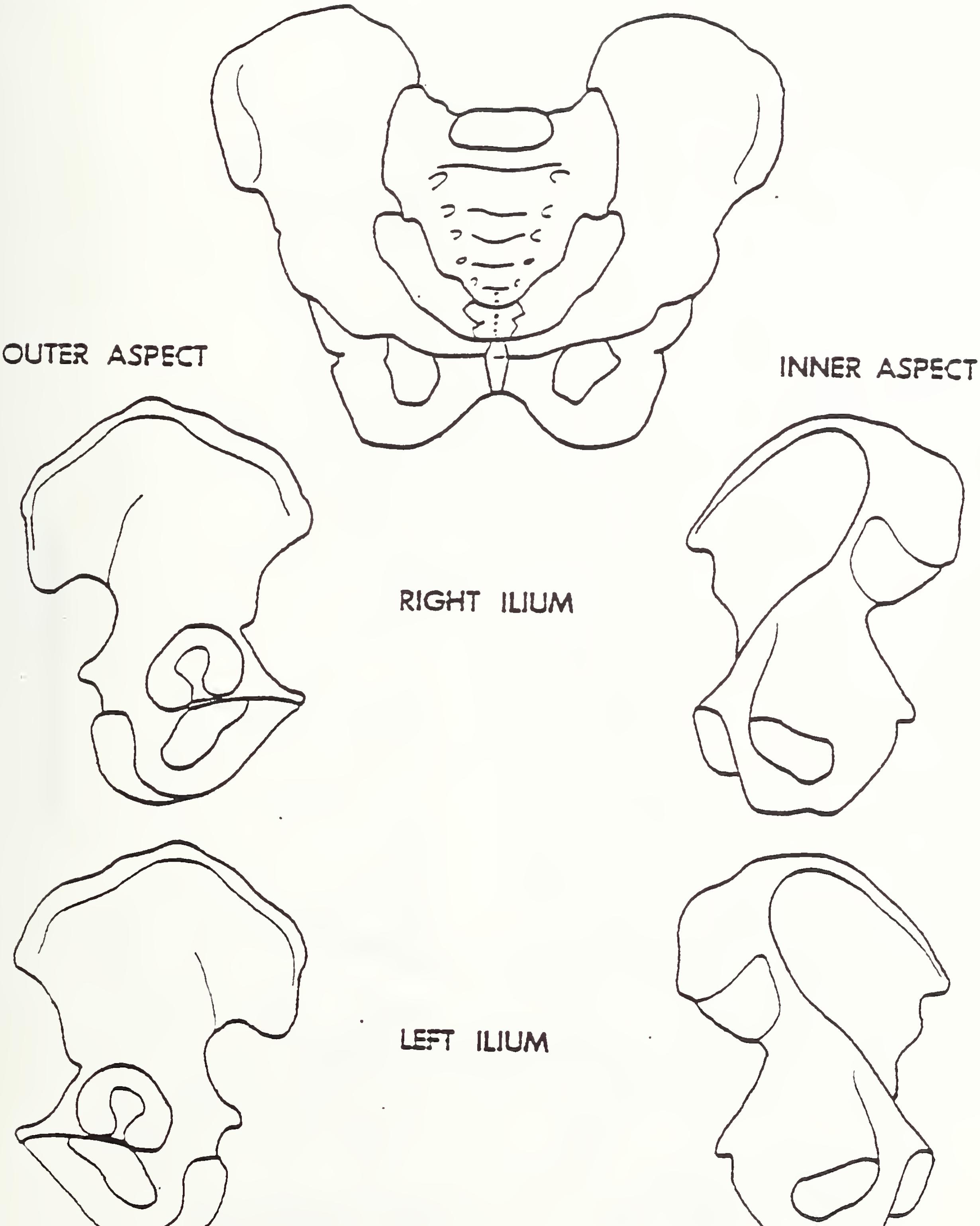
Anterior



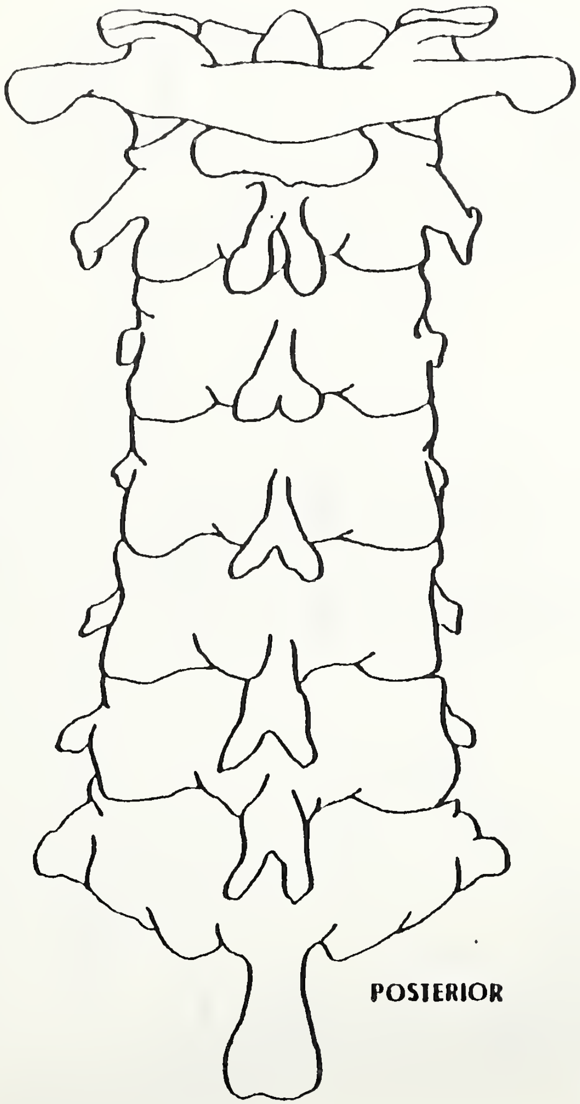
Posterior

LOWER EXTREMITIES

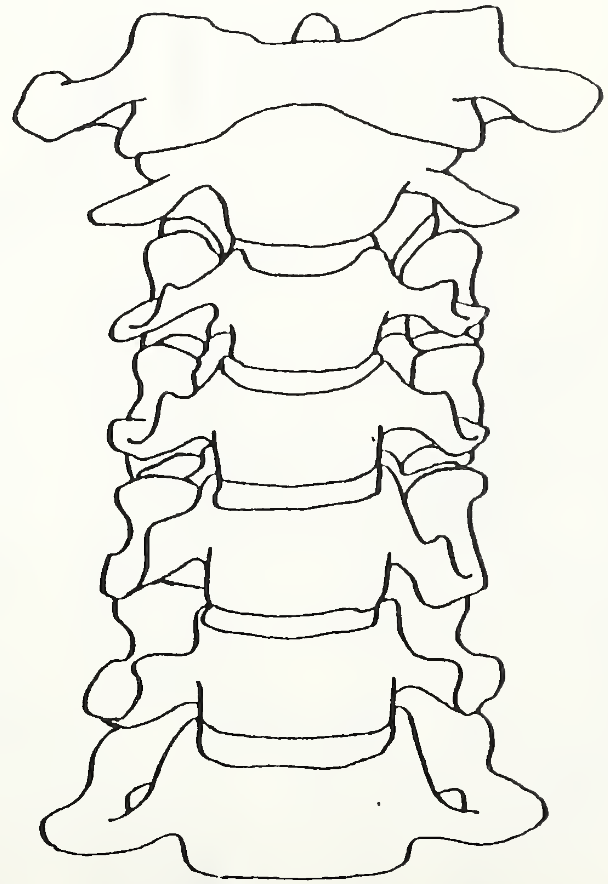
TEST NO. ____________________



TEST NO. ____________



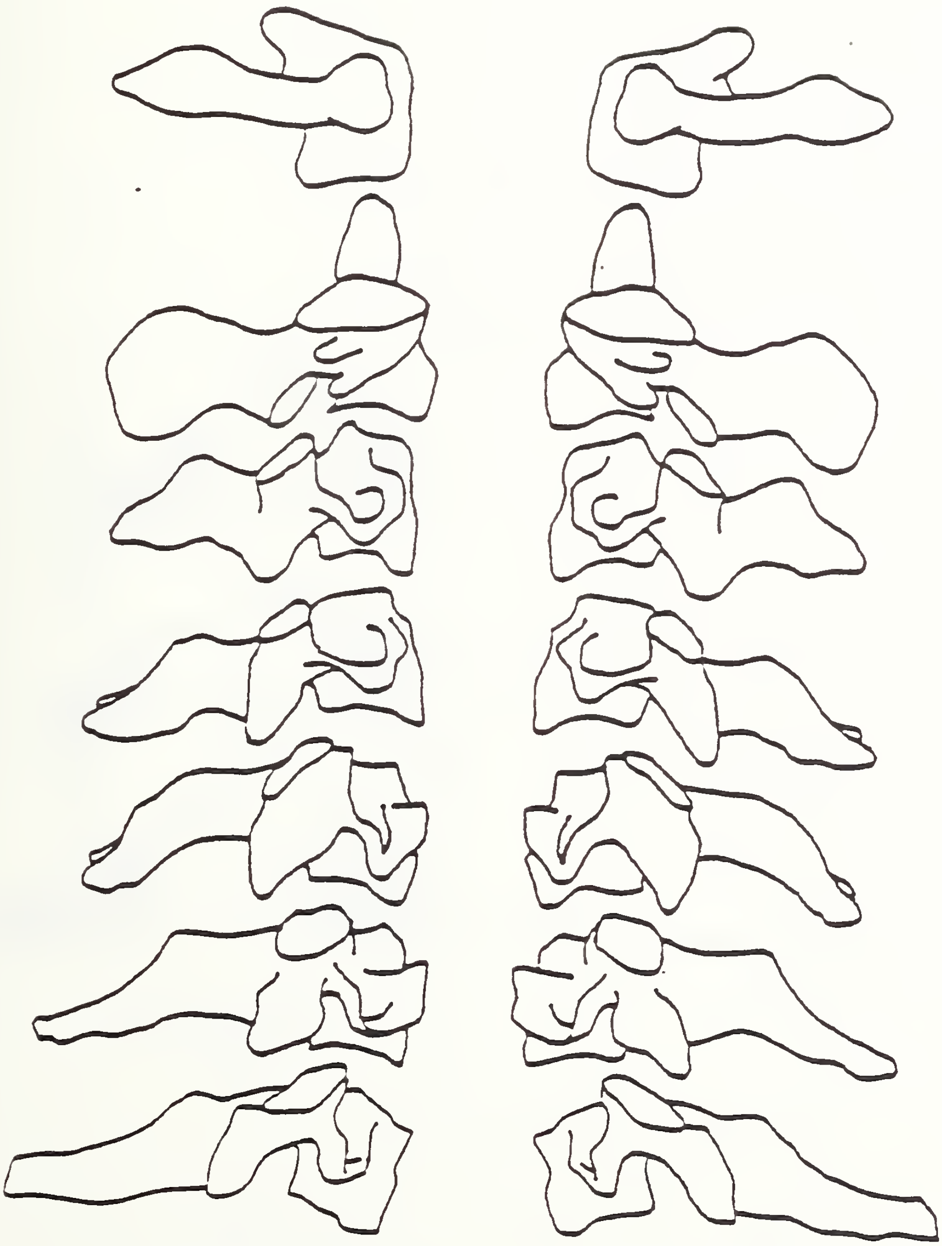
POSTERIOR



ANTERIOR

CERVICAL VERTEBRAE

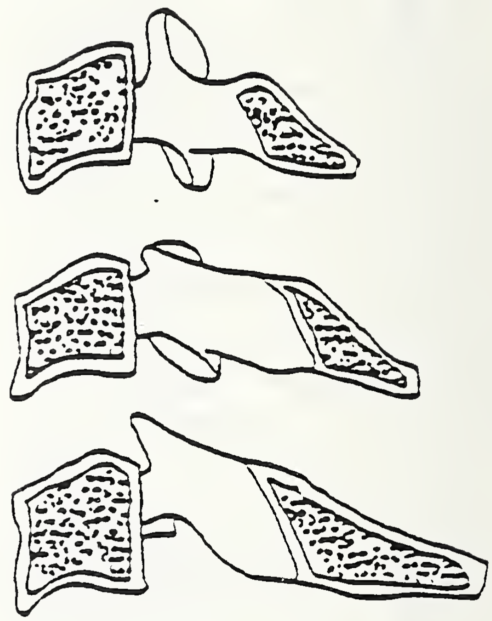
TEST NO. _______________



Right Profile

Left Profile

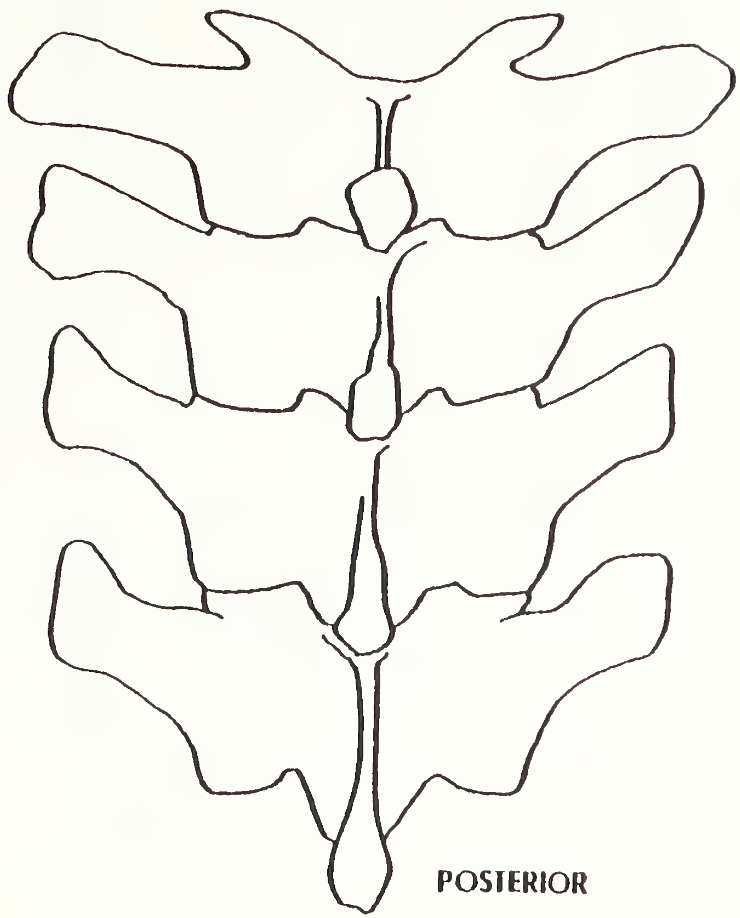
TEST NO. ______________



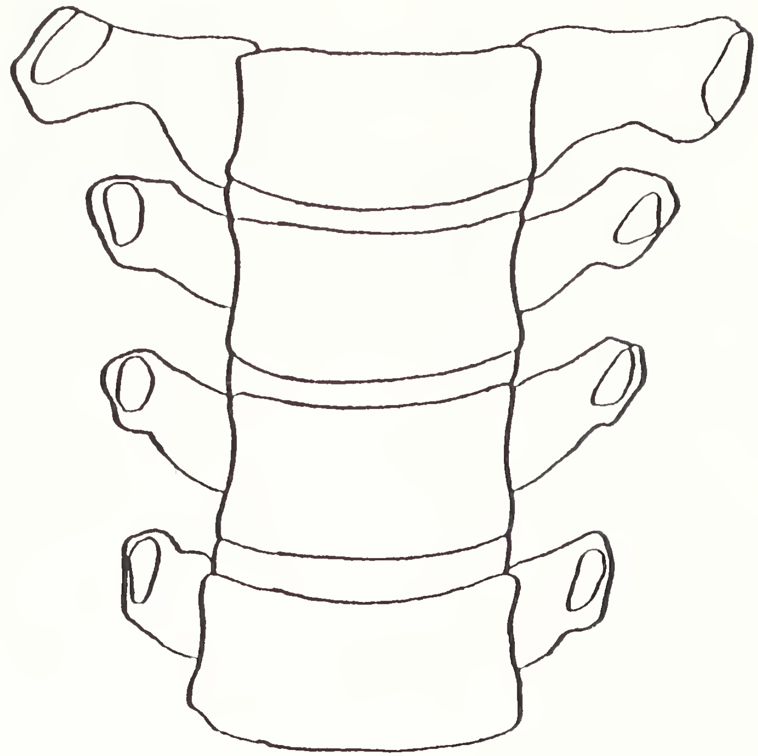
Cross Section

TEST NO. ____________

THORACIC VERTEBRAE (T1 - T4)



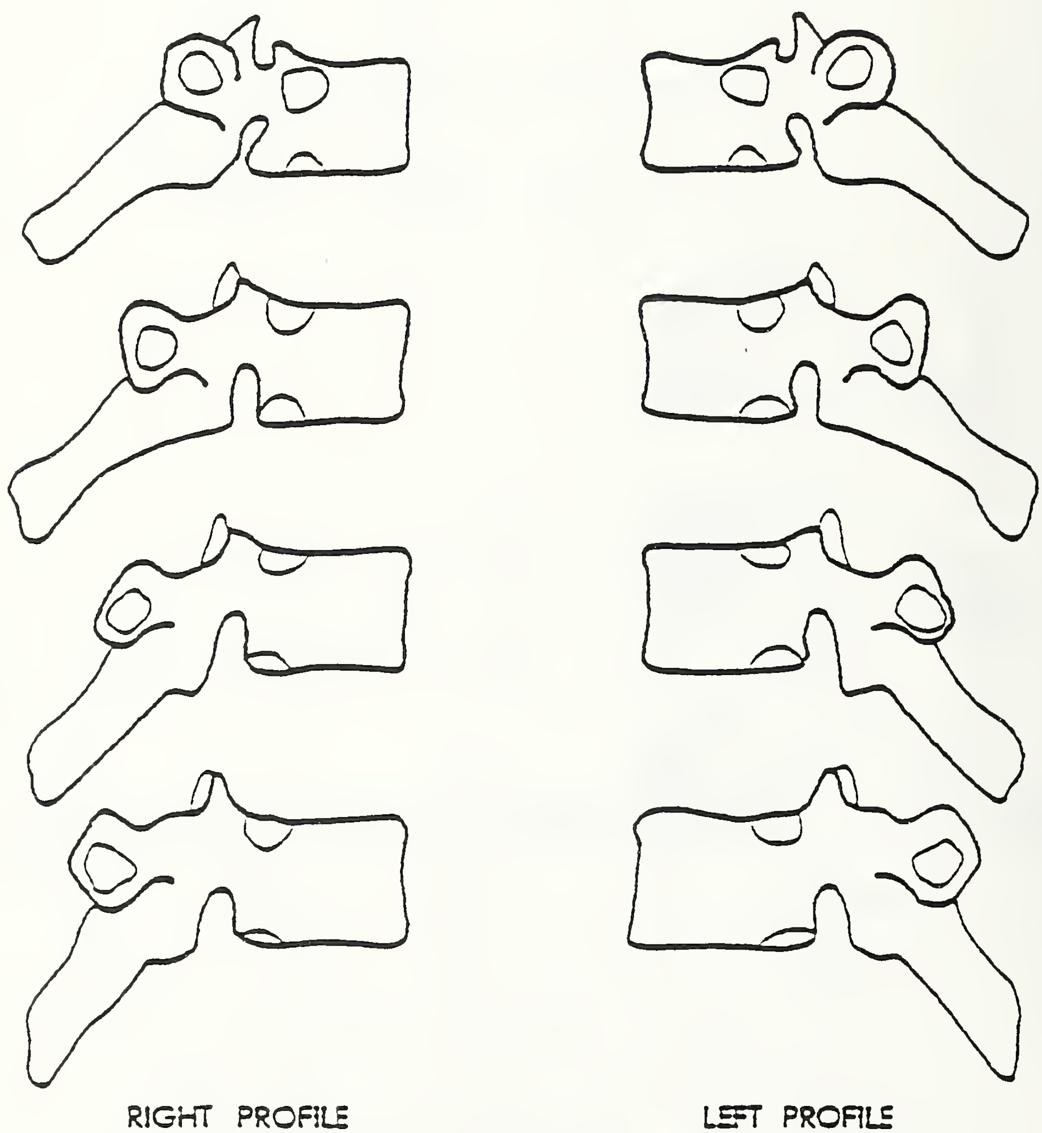
POSTERIOR



ANTERIOR

TEST NO. ______________

THORACIC VERTEBRAE (T1 - T4)



APPENDICES

Anatomy Room Setup
Sled Lab Setup
Cart Setup
Autopsy Setup
Timer Box Setup
Pendulum Wierdness

MEASUREMENT

___ Anthropometer

___ Metric measuring tape

PAPER AND PLASTICS

___ Visqueen on autopsy table

___ Blue pads on table

___ Gauze

TAPES AND STRINGS

___ Silver tape

___ Masking tape

___ Adhesive tape

___ Fiber tape

___ Flat waxed string

SCALPELS

___ 2 large (#8) handles

___ 2 medium (#4) handles

___ 2 small (#3) handles

___ 2 #60 blades

___ 5 #22 blades

___ 5 #15 blades

___ 2 #12 blades

FORCEPS

___ 2 hooked

___ 2 large plain

___ 2 small plain

HEMOSTATS

___ needle

___ small straight

___ small curved

___ large straight

___ large curved

SCISSORS

___ 2 small

___ 2 medium

___ 2 large

SPREADERS

___ 2 large

___ 2 medium

NEEDLES

___ 2 double curved

___ 8 Trocar with stainless steel lockwire

___ 2 5cc sringes

CLOTHING

___ Tampons

___ Thermoknit longjohns and top

___ Cotton socks

___ Blue vinyl pants and top

___ Head and body harnesses

PRESSURIZATION

___ Modified Foley (#18 or #20) balloon catheters

___ Kulite shield

___ Tracheal tube

___ Right and left carotid pressurization catheters (Foley #10-14)

___ Cerebral spinal catheter (Foley #14-16)

___ Respiratory pressure tank

___ Manometer

___ Fluid pressure tank

___ 7% saline solution with India ink

BOLTS AND SCREWS

___ 6 self-tapping lag bolts

___ 3 lengths of wood screws

___ 1-72 screws

___ 10-32 tap

___ Strain relief bolt

___ Wood and metal self-tapping screw boxes

MOUNTS

___ Spine(2)

___ Rib (2, triax)

___ Rib (2, uniax, R-L)

___ Nine-accelerometer plates (large, small, and 8 feet)

___ Sternum

___ Substernale

___ Suprasternale (triax)

___ Dental acrylic

___ Bone wax

TOOLS

___ Electric hair clippers

___ Electric drill

___ Drill bits (No. 7, approx. 1/16", etc.)

___ large and small screwdrivers

___ nut driver (for lag bolts)

___ wire twisters

___ bone shears

___ Executive Slinky object space calibrated and nearly functional

MATERIALS

___ balsa wood

___ rags

___ foam (at least 2 sheets of 3x4 ft 6")

___ Ensolite

___ Styrofoam

___ Dow Ethafoam

___ Overhead support bar

ROPE CUTTERS

___ head, 1/8"

___ pendulum (with spring, 3/16")

___ nylon strings (10 24" 3/16"; 10 18" 1/8")

___ shock absorber and styrofoam bumper

WEIGHTS

___ steel blocks on pendulum

MISCELLANEOUS

___ calculator

___ bone wax

___ Pressurization equipment (pulmonary, thoracic arterial, head arterial, cerebral spinal)

___ Timer box

___ Strobes

___ Head impact back brace and foam padding

TAPES

___ adhesive

___ fiber

___ silver

___ masking

___ black

___ double stick

PAPER AND PLASTIC

___ blue pads

___ gauze

___ gloves

___ plastic garbage bags

SCALPELS

___ 1 medium (#4) handle

___ 1 small (#3) handle

___ 2 #22 blades

___ 2 #15 blades

___ 1 #12 blade

SURGICAL TOOLS

___ 2 forceps

___ 2 hemostats

___ large scissors

___ 2 double curved needles

STRING

___ flat waxed string

___ black thread

TOOLS

___ small (1-72) screwdriver

___ large screwdriver

___ nut driver

___ ball driver (6-32, 0-80)

___ 1-72 screws

___ 2-56 screws

___ 0-80 screws

___ wiretwisters

MISCELLANEOUS

___ ball targets

___ paper targets

___ bone wax

___ vaseline

___ Q-tips

___ tubing connectors

___ tie wraps

___ lockwire

___ 50cc syringe

___ pulmonary pressurization relief valves

AUTOPSY SETUP

PAPER AND PLASTICS

___ Visqueen on autopsy table

___ blue pads

___ gauze

TAPE

___ silver tape

___ masking tape

___ fiber tape

SCALPELS

___ 2 large (#8) handles

___ 2 medium (#4) handles

___ 2 small (#3) handles

___ 2 #60 blades

___ 5 #22 blades

___ 5 #15 blades

___ 2 #12 blades

FORCEPS

___ 2 hooked

___ 2 large plain

___ 2 small plain

HEMOSTATS

___ needle

___ small straight

___ small curved

___ large straight

___ large curved

SCISSORS

___ 2 small

___ 2 medium

___ 2 large

SPREADERS

___ 3 medium

___ 3 large

MISCELLANEOUS

___ Stryker saw and blade

___ bone shears

___ wedge

___ rib cutters

TIMER BOX SETUP

EQUIPMENT Impact	TIMER VALUES Delay		Run
Gate (from strobe 1)	0012-y	1	0150
Lights (start)	0001	2	2600
HyCam (start)	1200	3	1600
Pendulum rope cutter(start)	2200-x*	4	0050
Photosonics (start)	1000	5	1600
		6	
Head, pelvis, rope cutter (from velocity probe)	0001	7	0050
Piston Acceleration Corridor	1 + Z	8	0050-0150

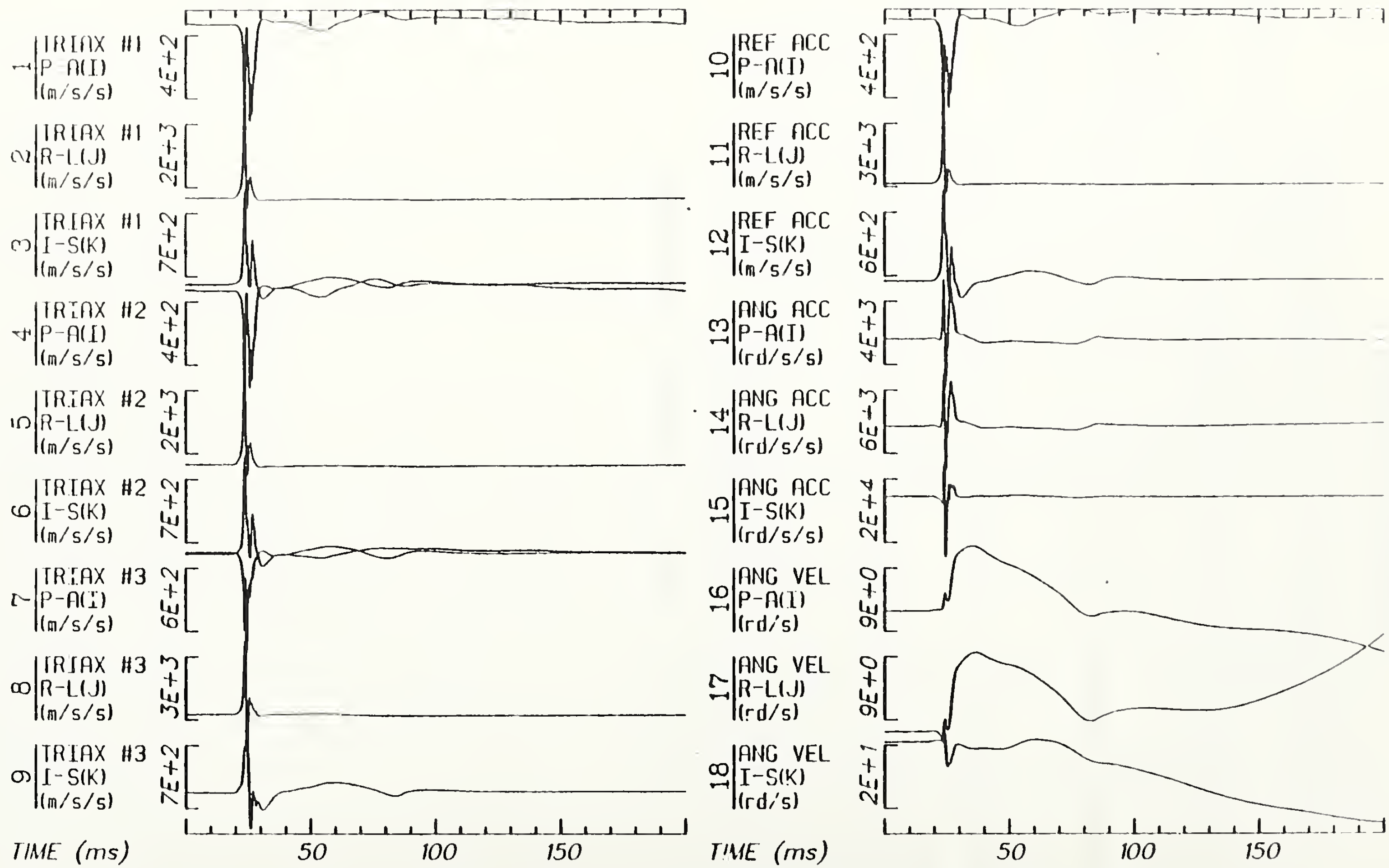
* x obtained from elliptic integral of the first kind. For 100° .87 sec, 20 ° .70 sec. y=angle/20 Z=210/angle

PENDULUM WEIRDNESS

Average	60.84	61.00	61.26	61.56
Standard Deviation	±.28	±.37	±.05	±.23
Period	3.042	3.050	3.063	3.078
(MGL/I)÷2	2.065	2.060	2.051	2.041
t/2pi	.484	.485	.487	.489

11.0 APPENDIX C

HEAD IMPACT SERIES - SELECTED TIME-HISTORIES



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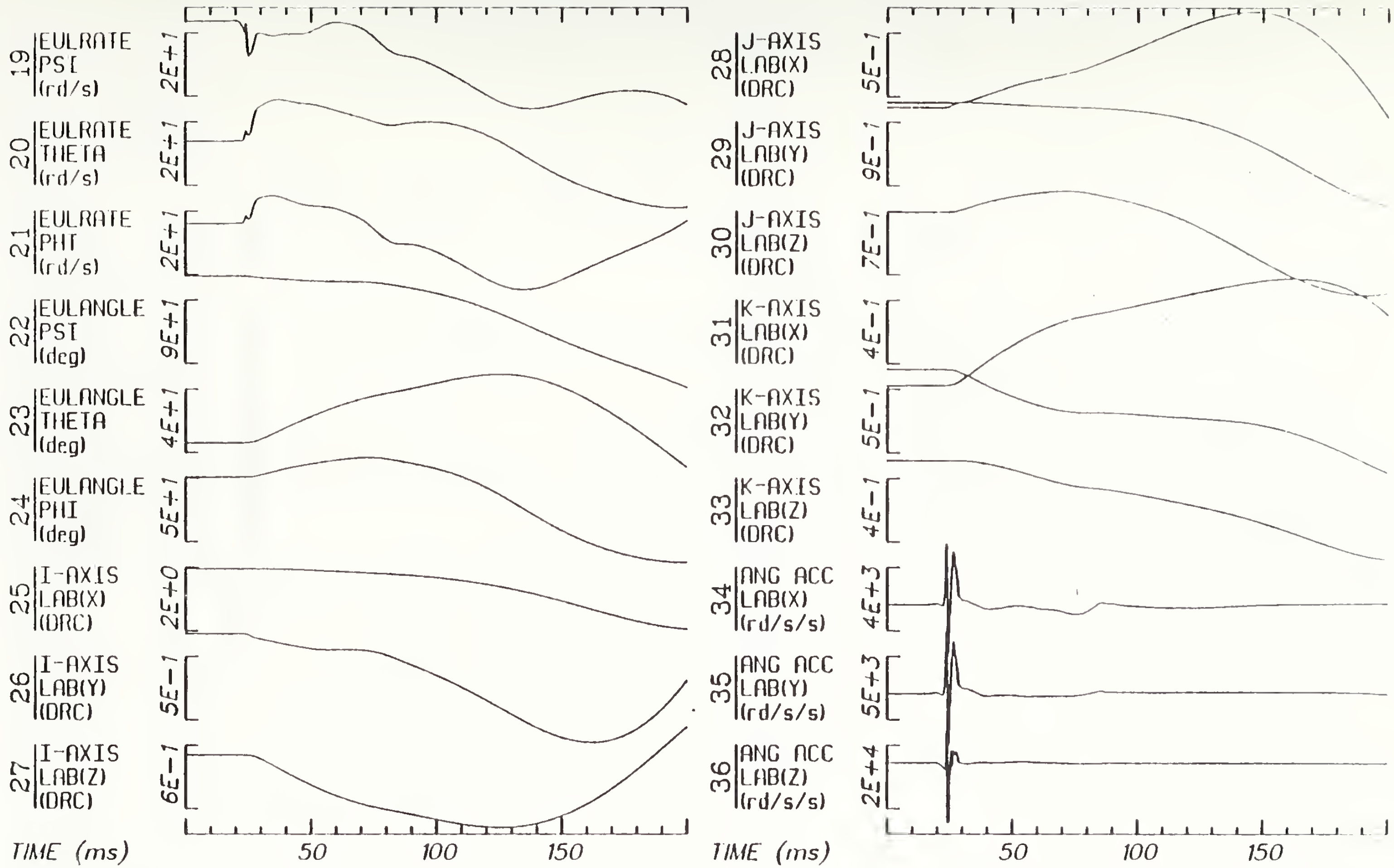

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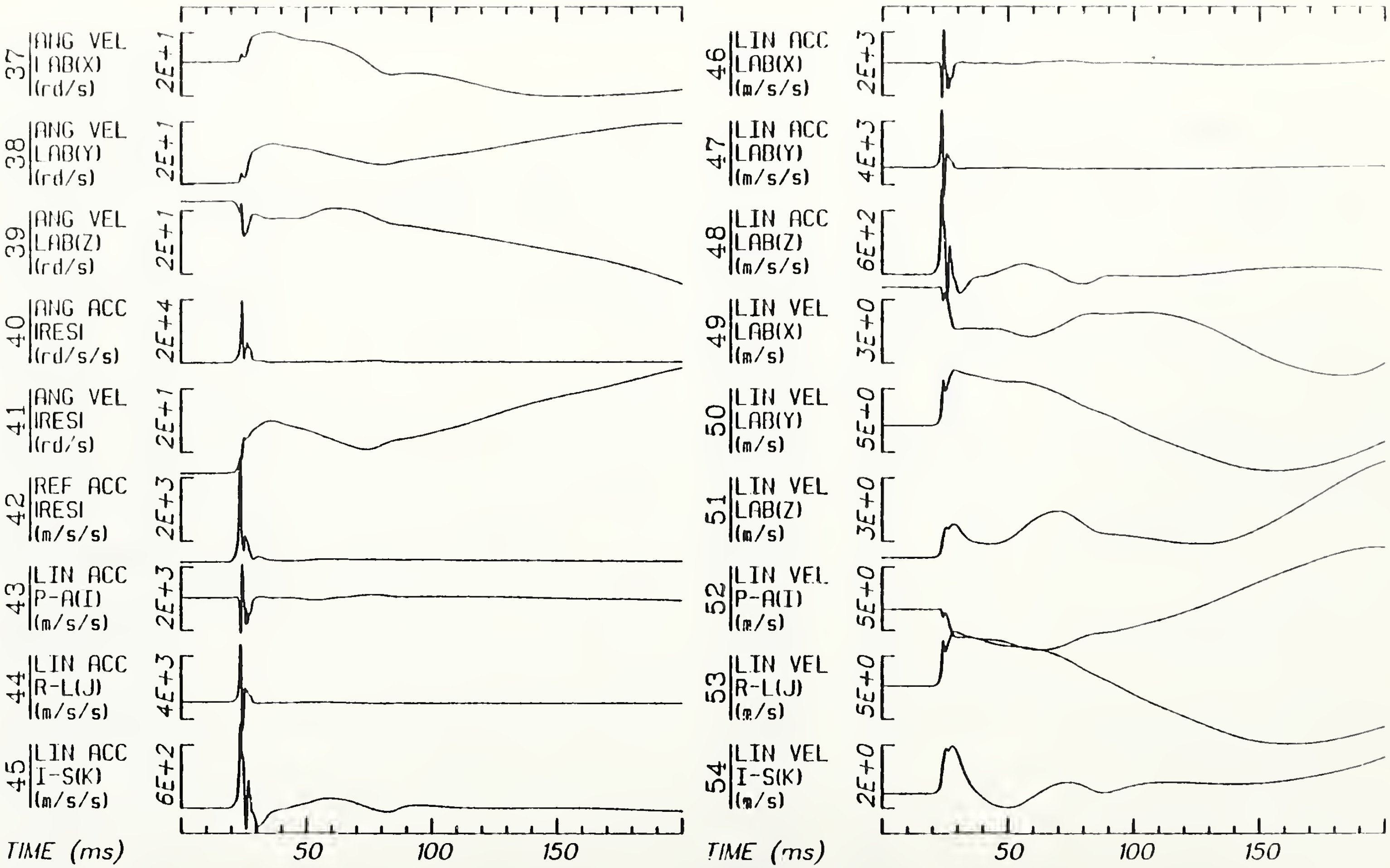

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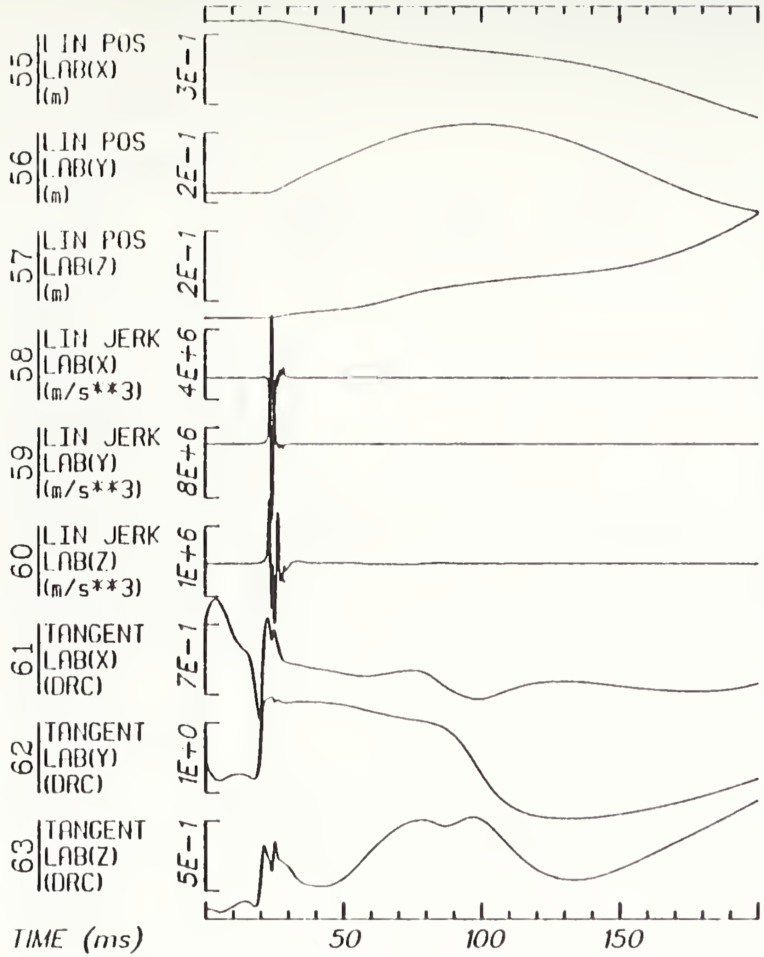

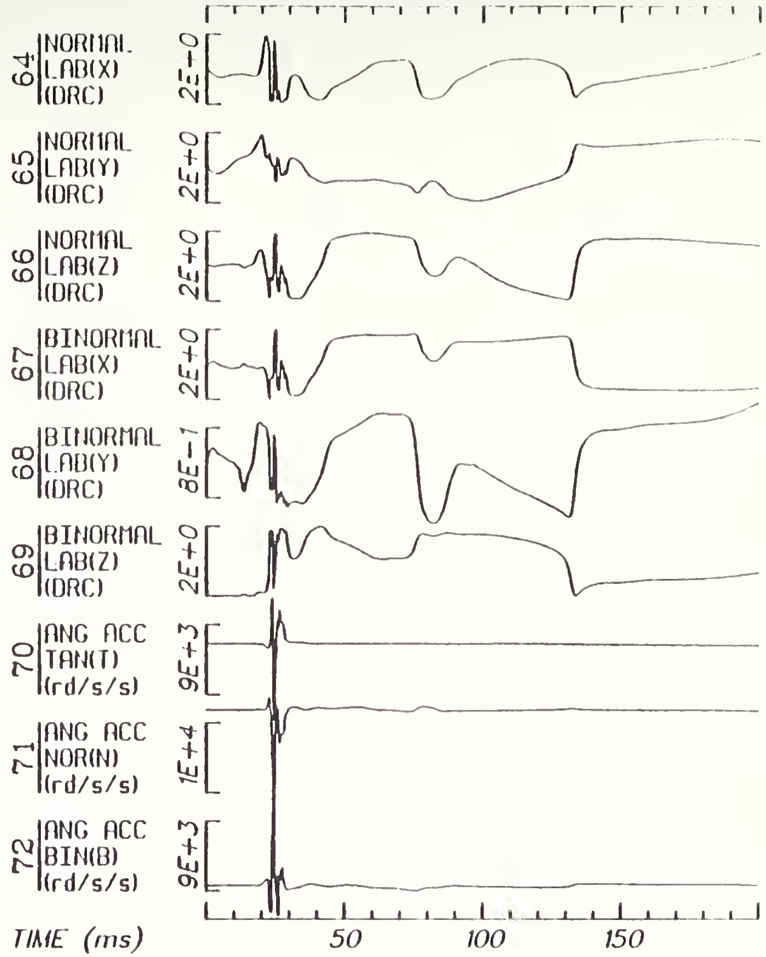

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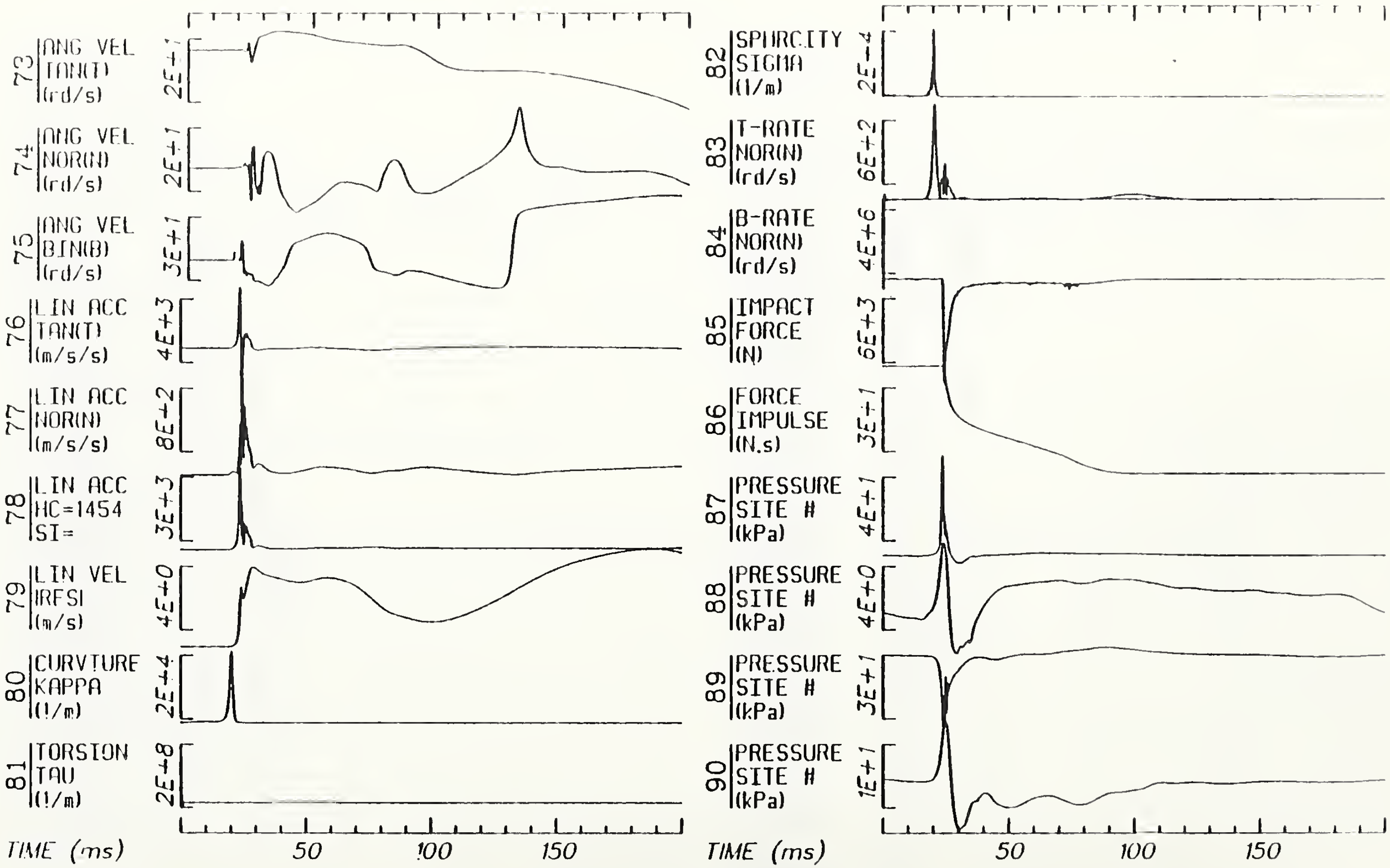

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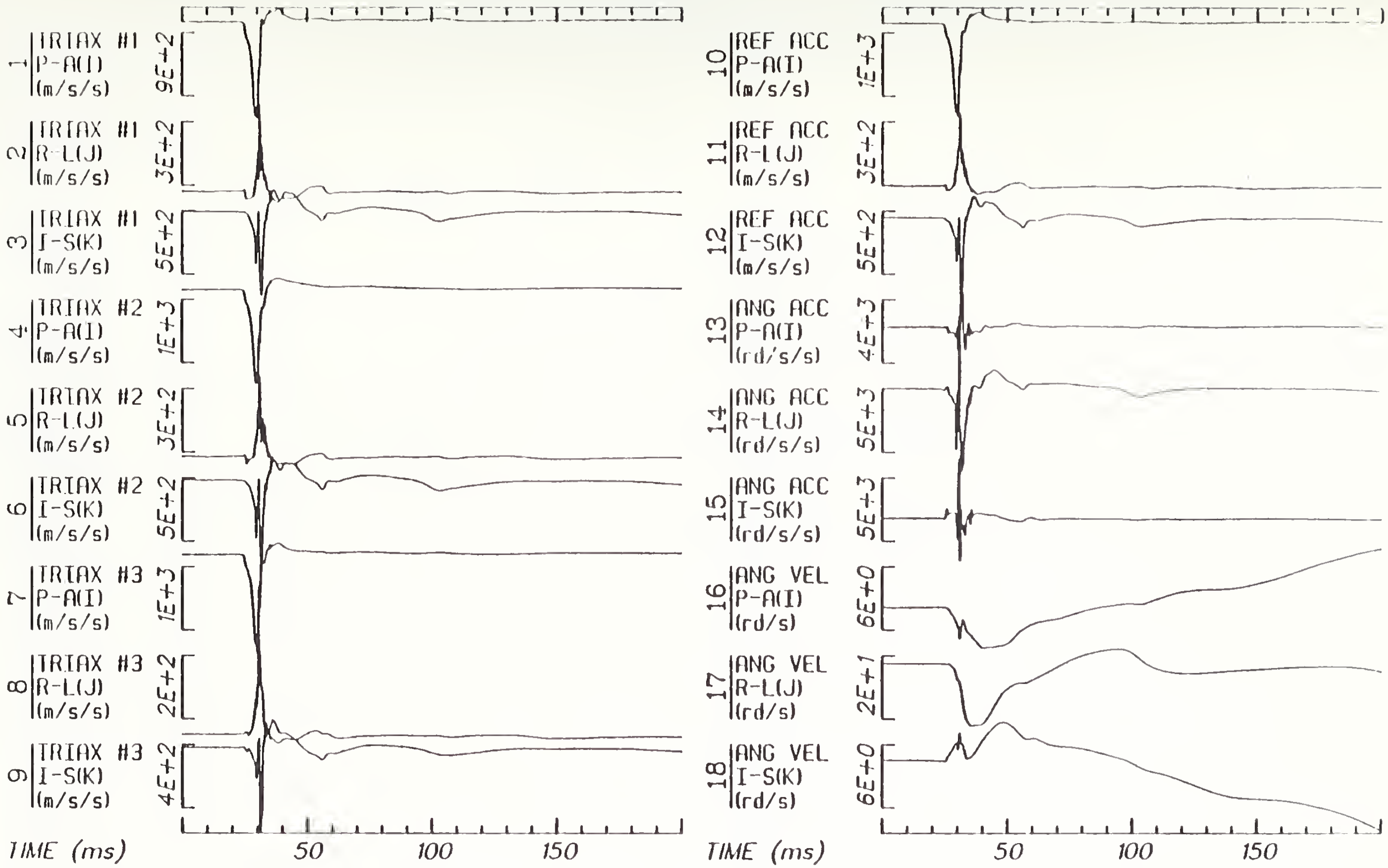
CG



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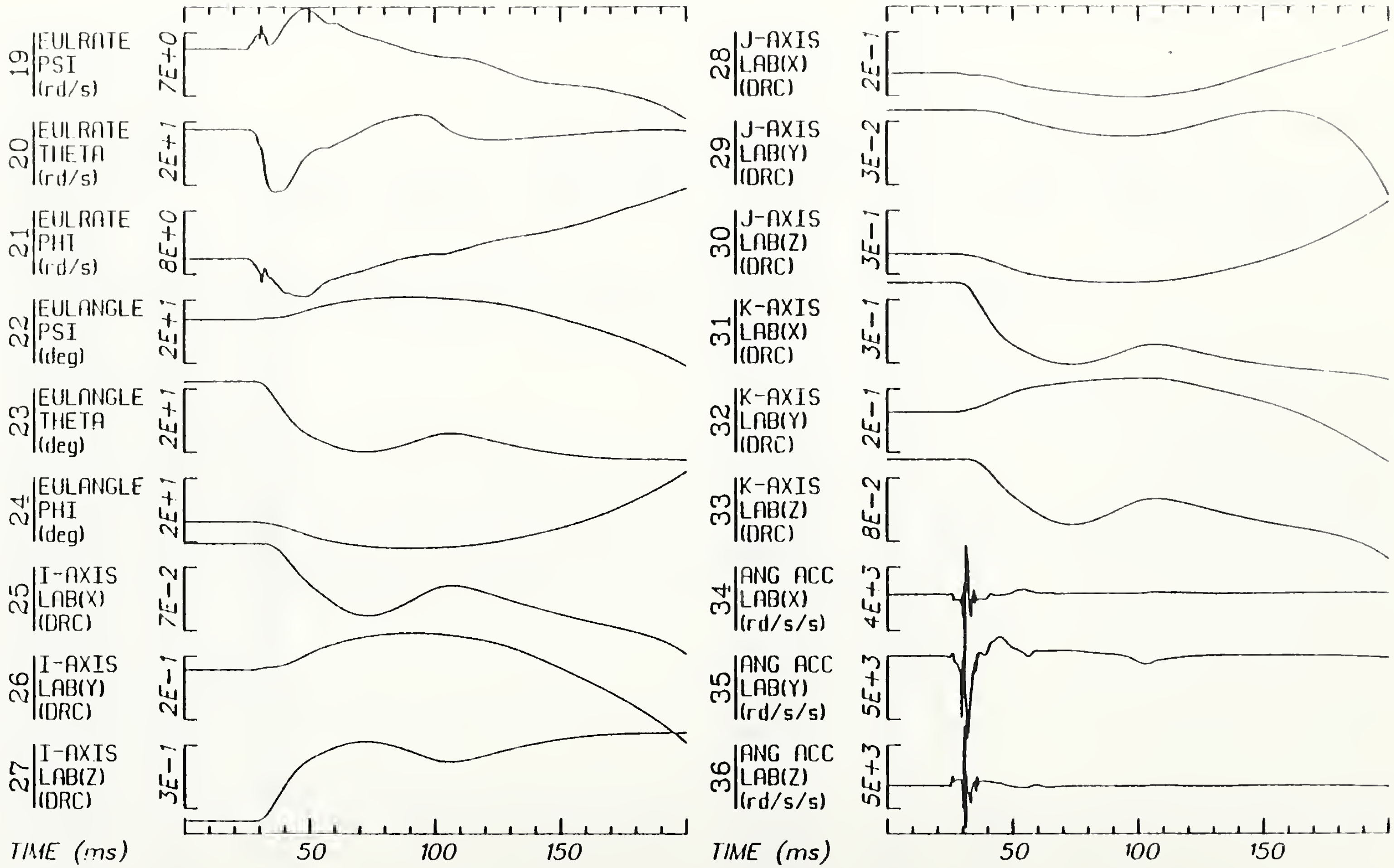

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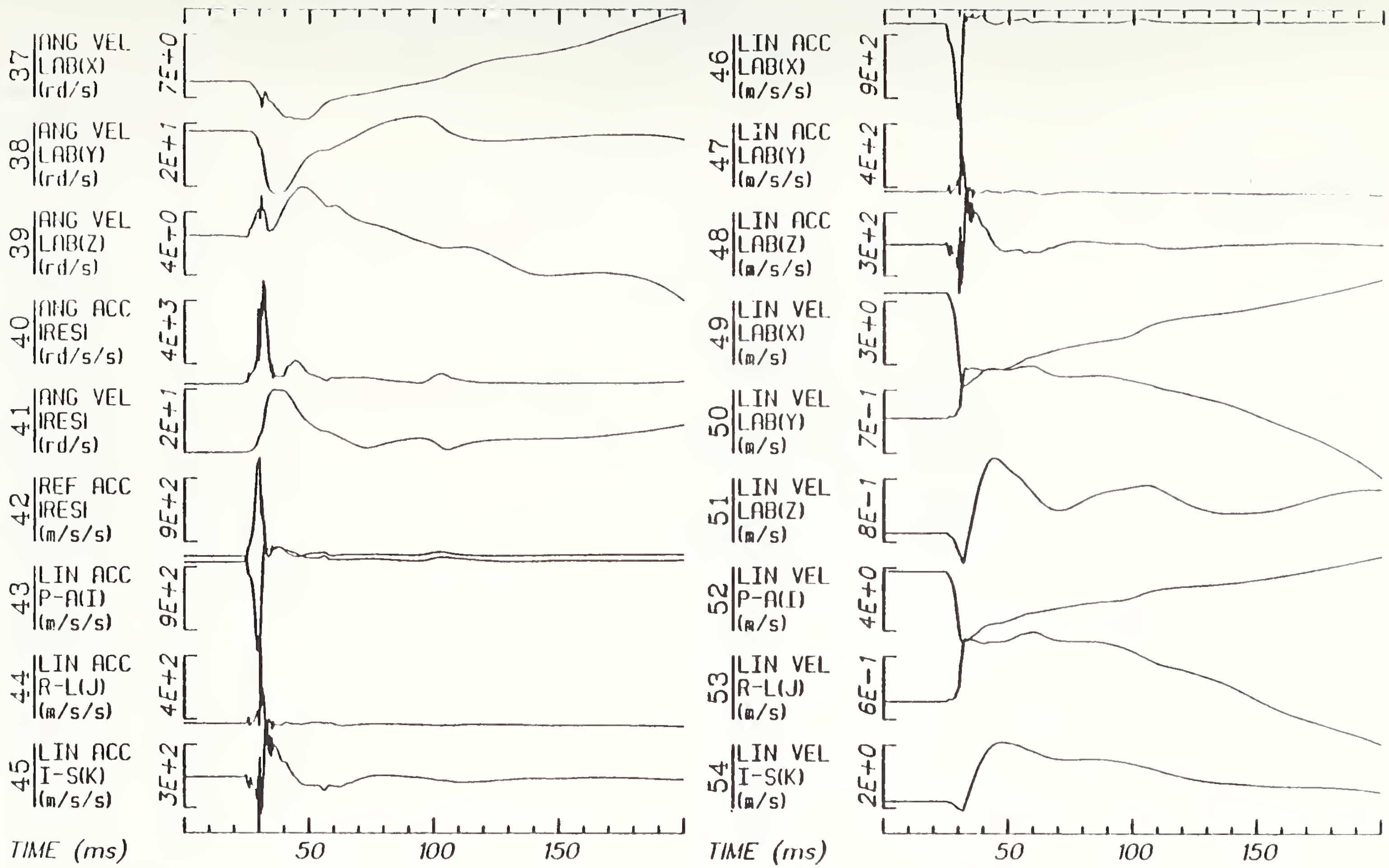

Run ID: 82E021 Disk: -HEAD File: 2 Date: MAR 11, 1985 Sheet 3

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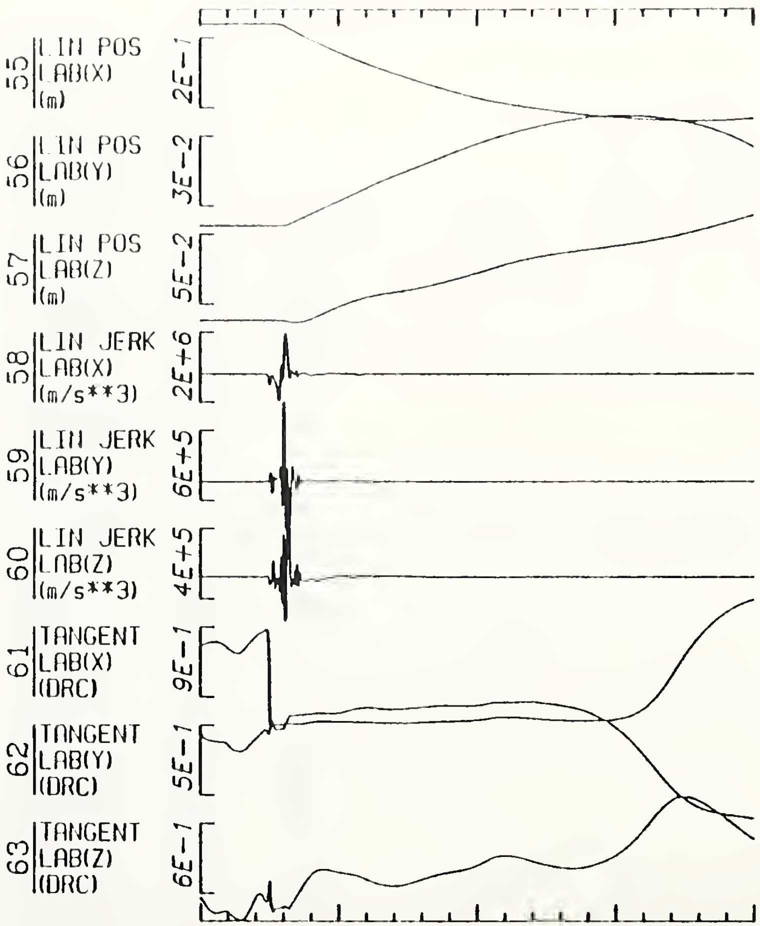
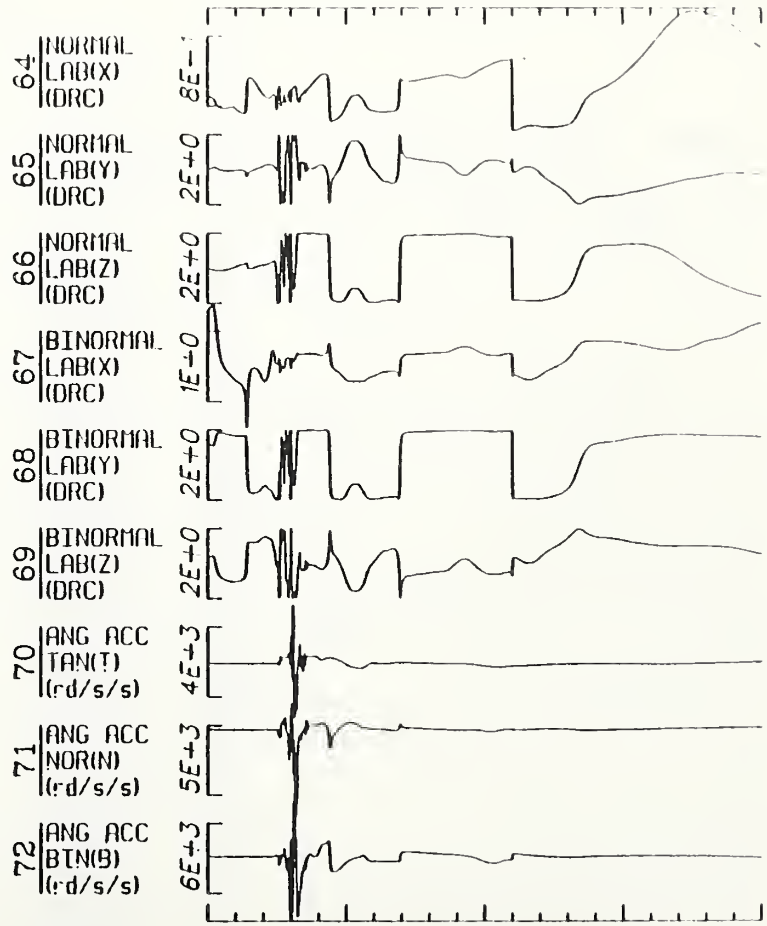
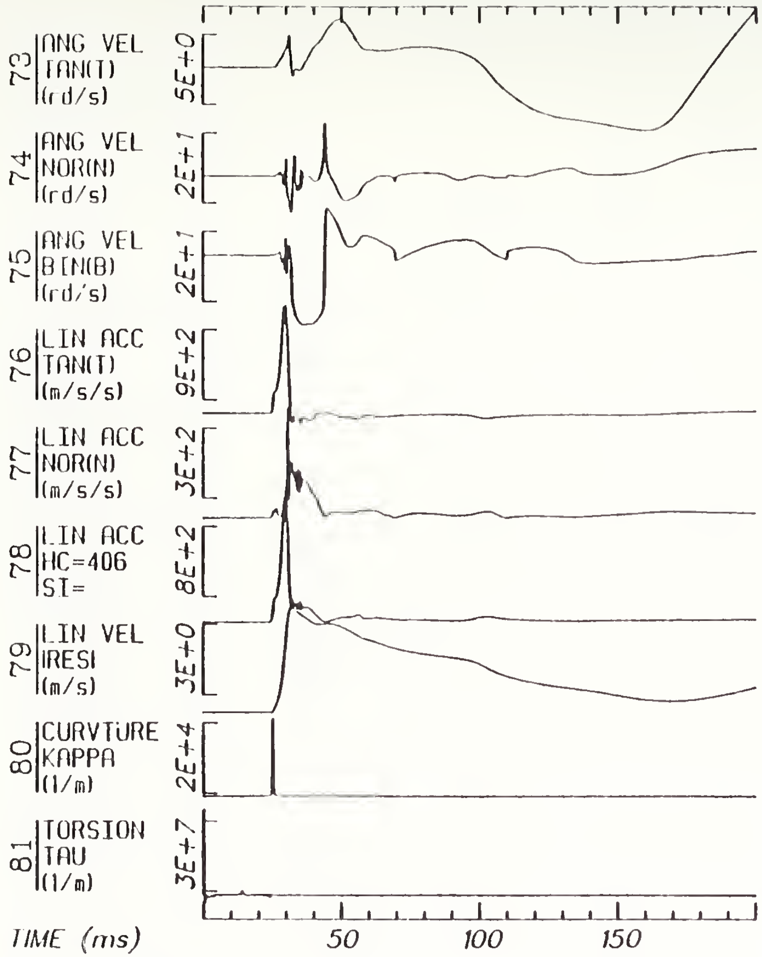
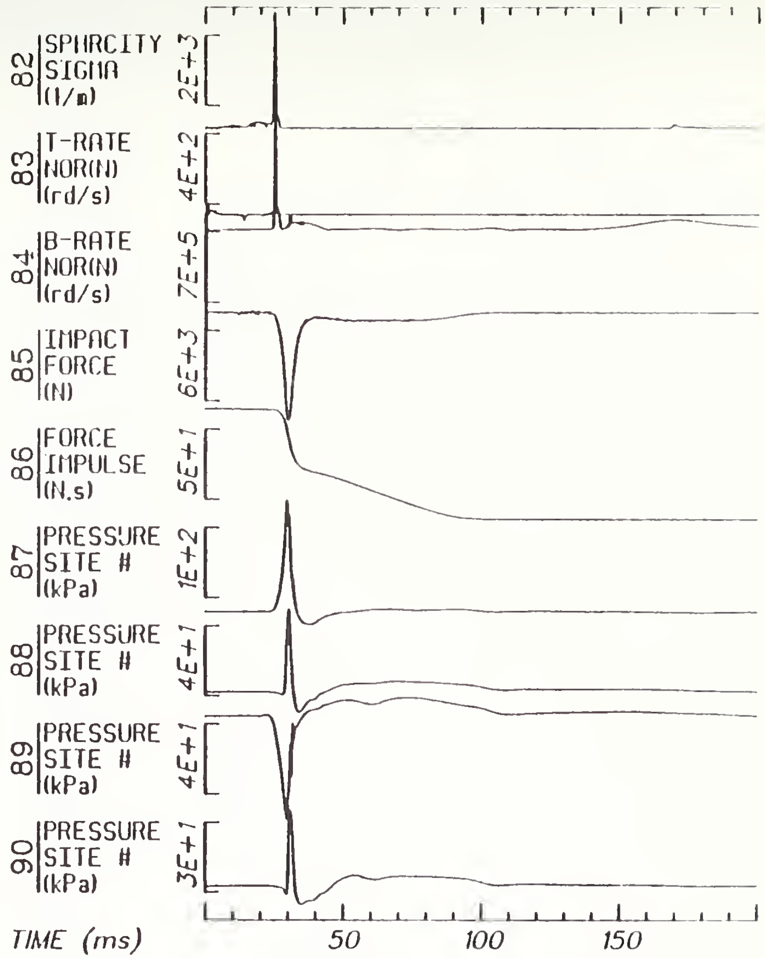




Run ID: 82E021 Disk: -HEAD File: 2 Date: MAR 11, 1985 Sheet: 4

*Filter:1600*4C*





Run ID: 82E021 Disk: -HEAD File: 2 Date: MAR 11, 1985 Sheet: 5

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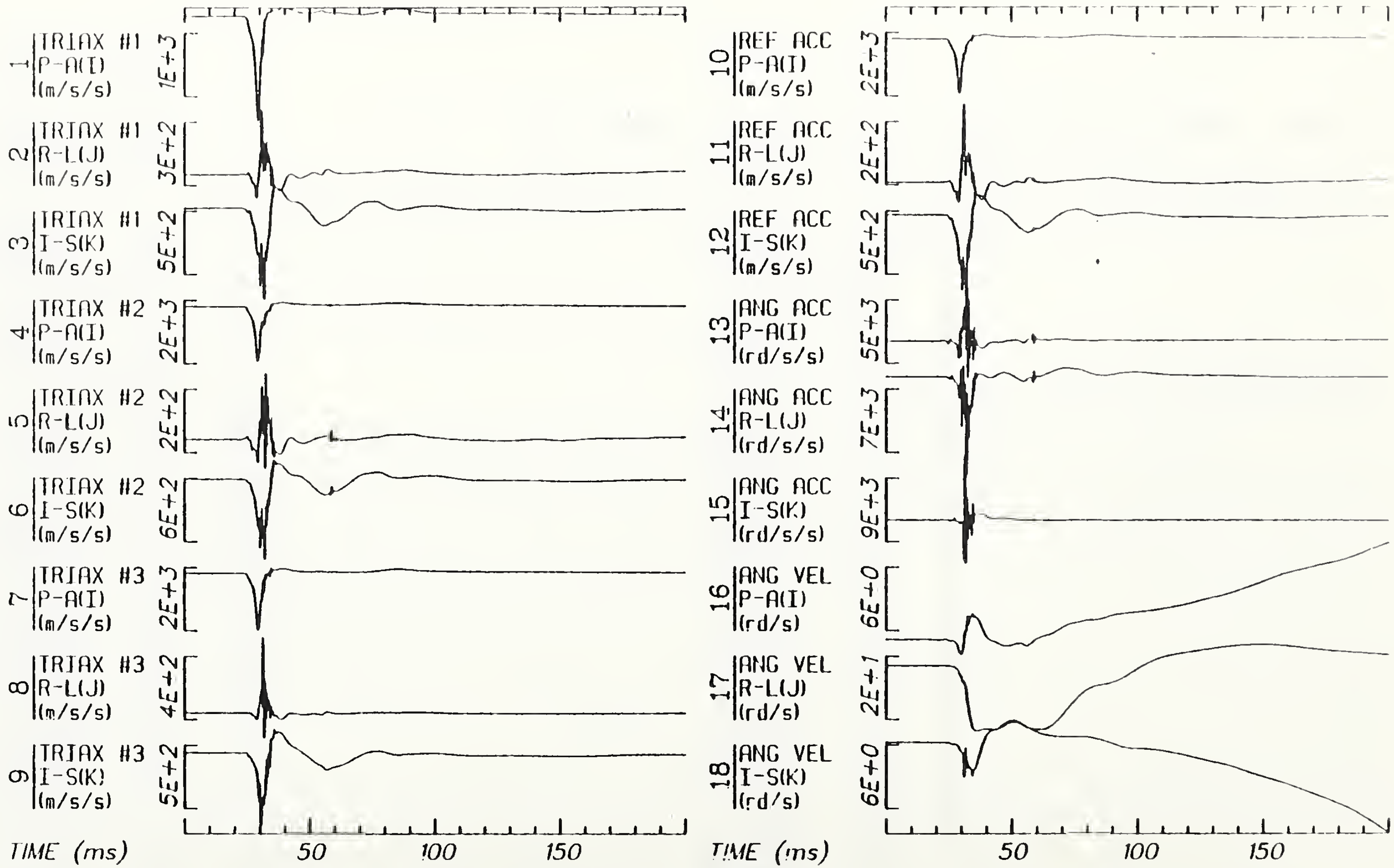

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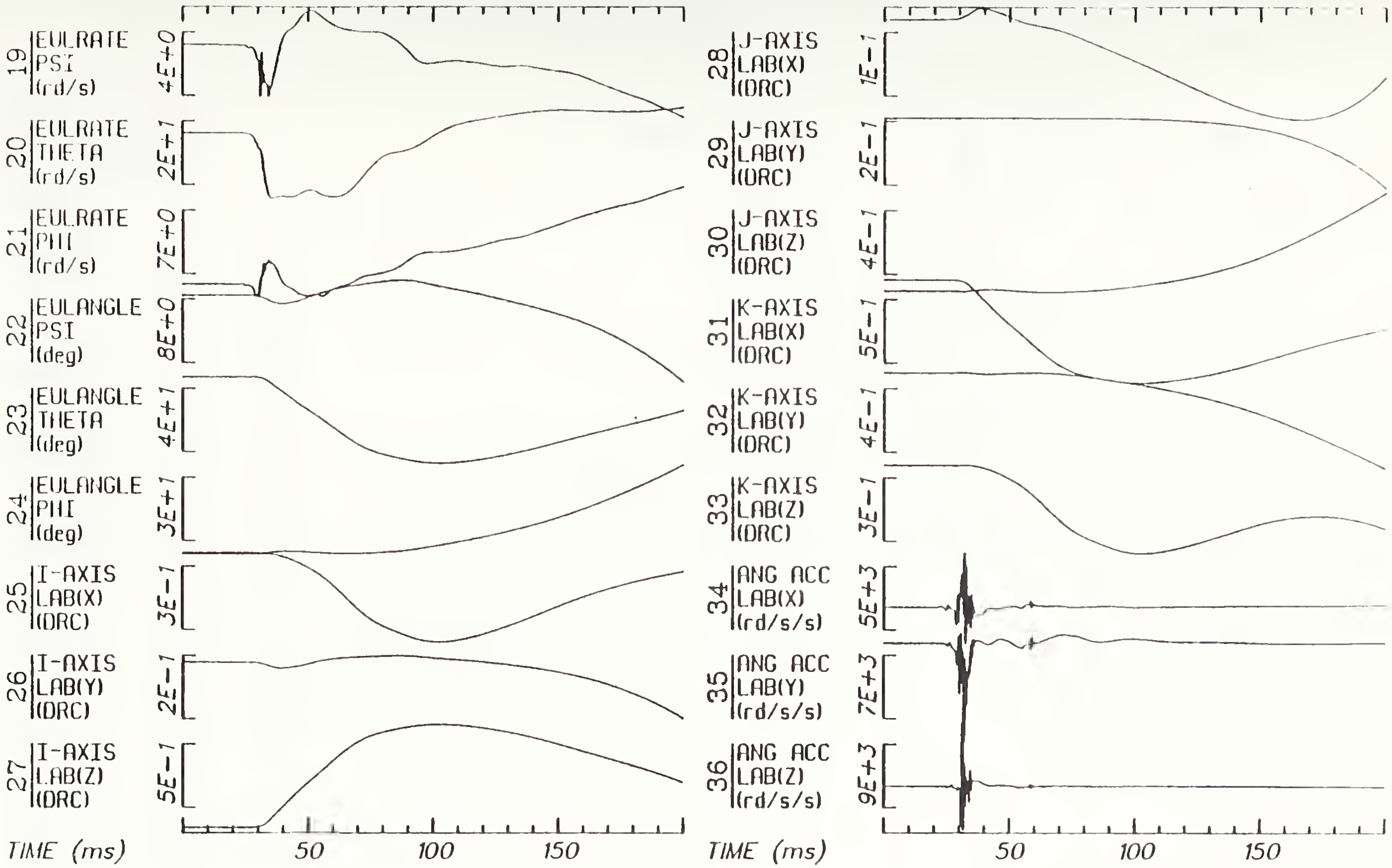

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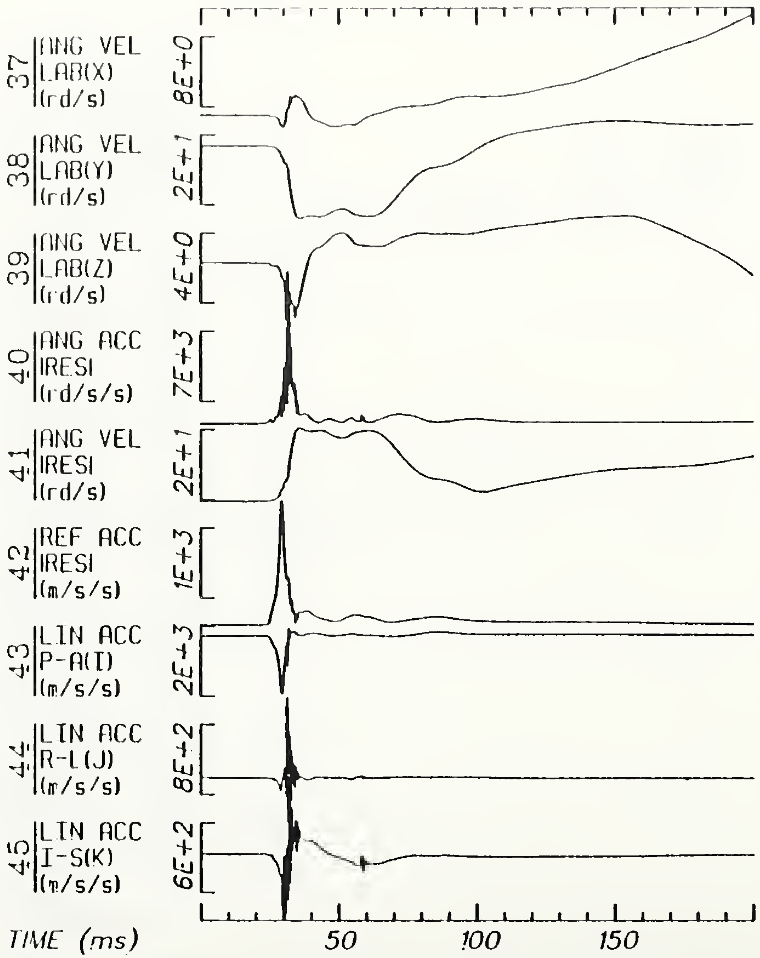

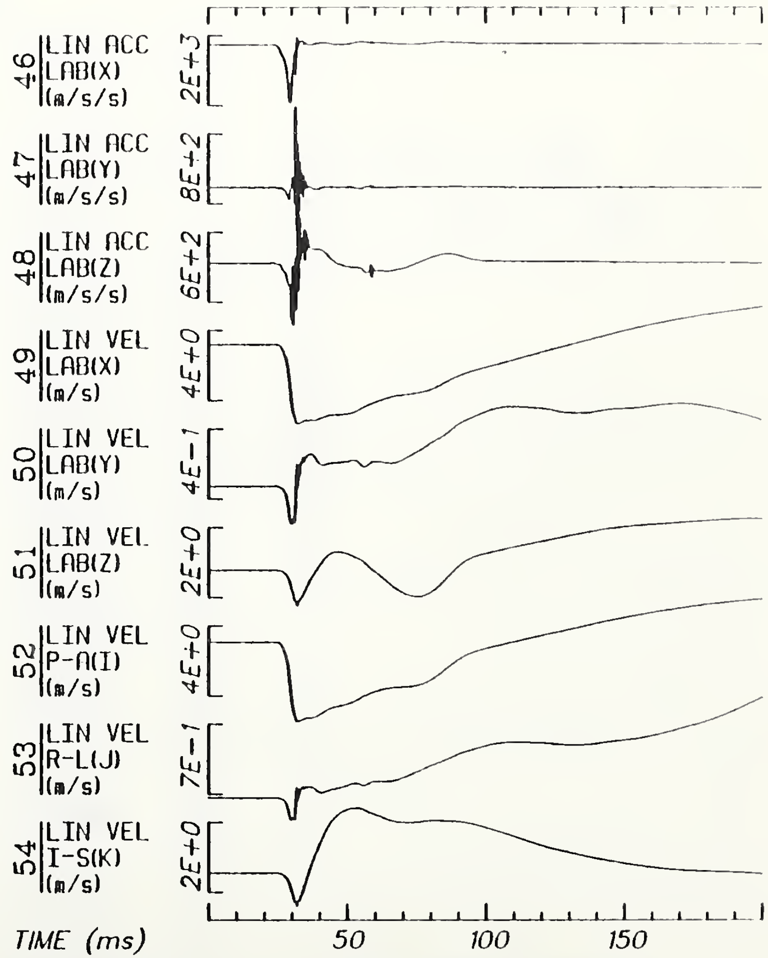

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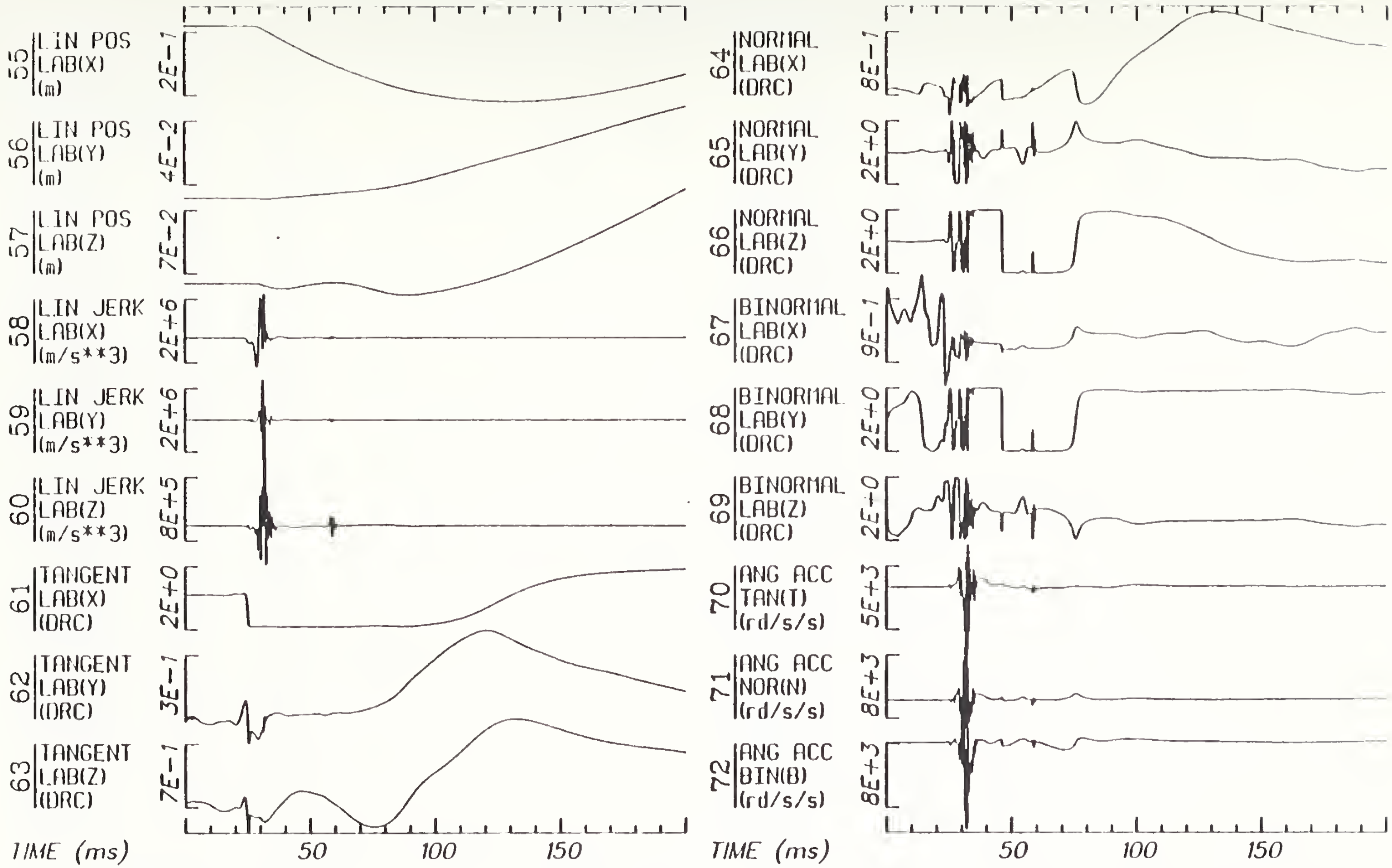

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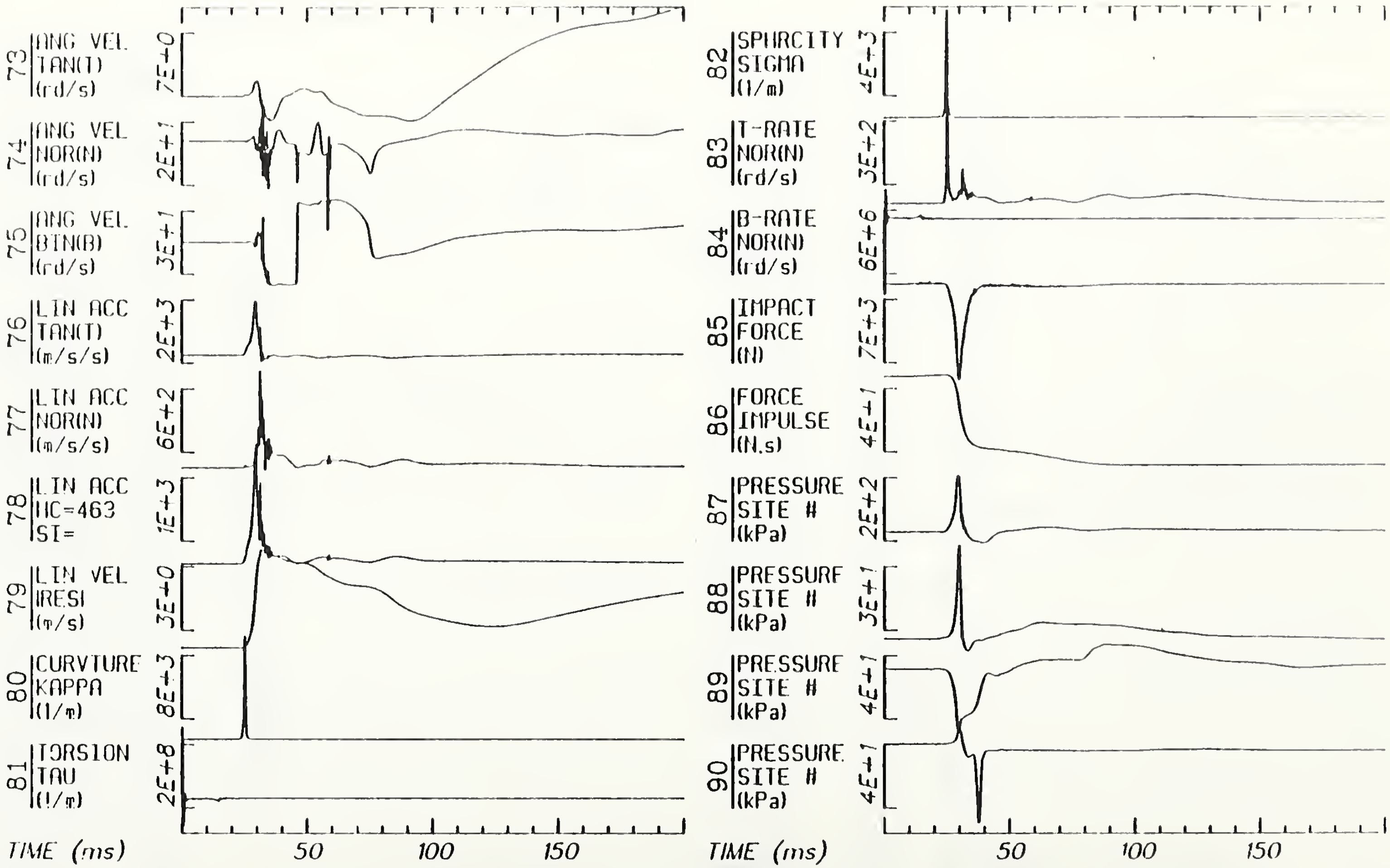

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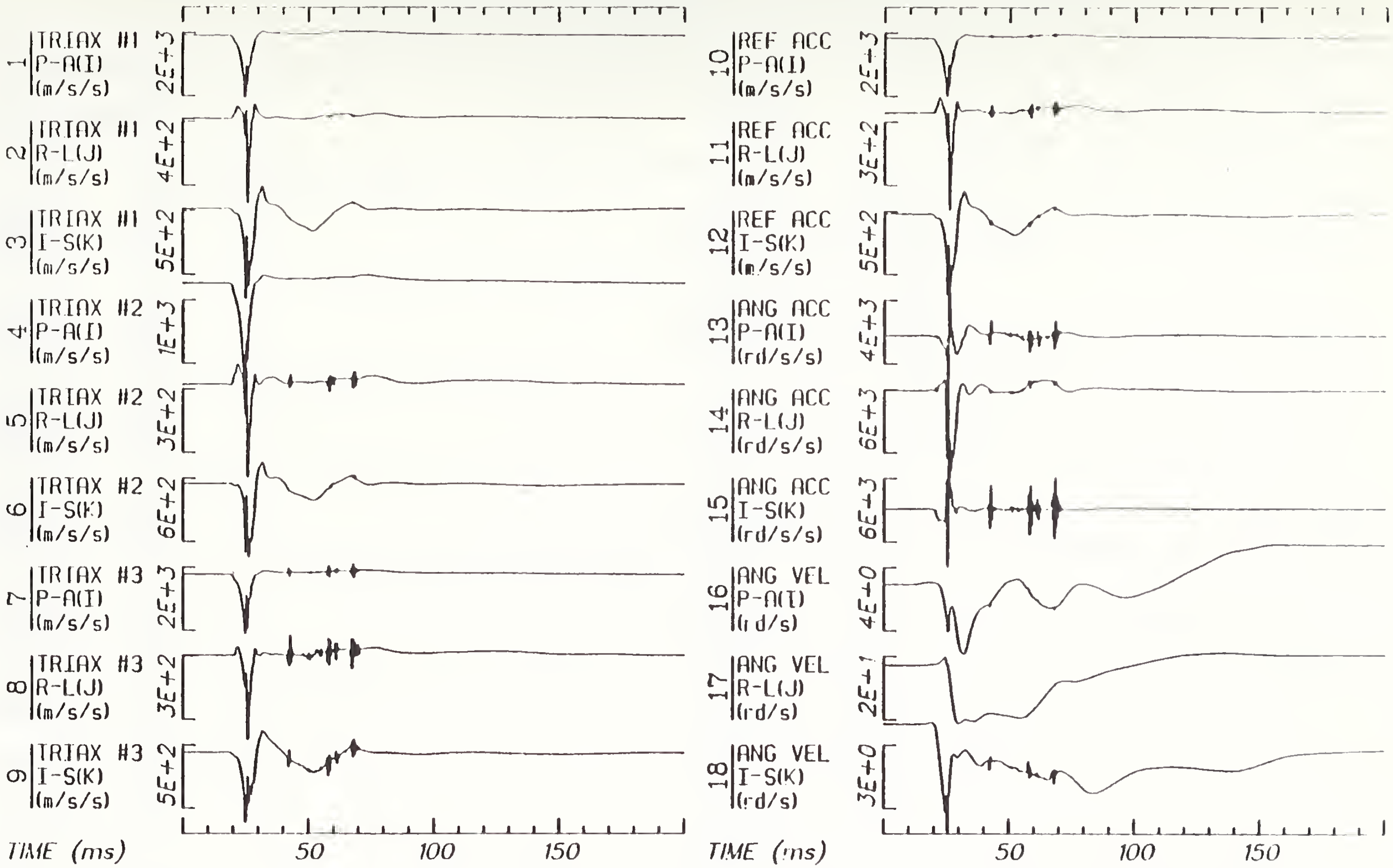

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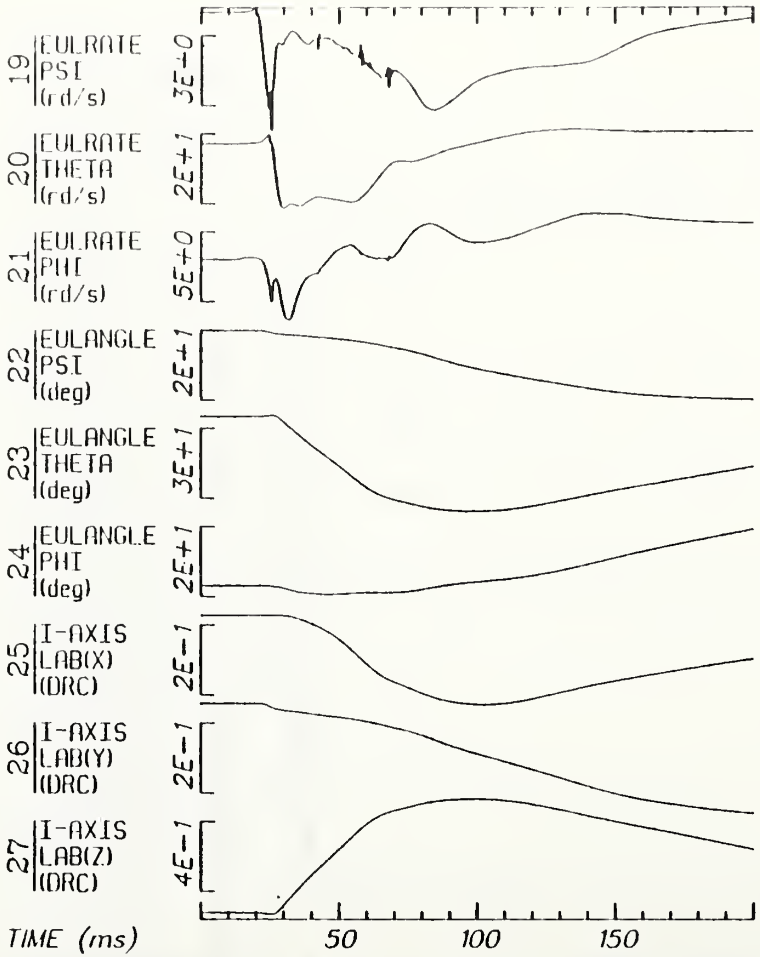

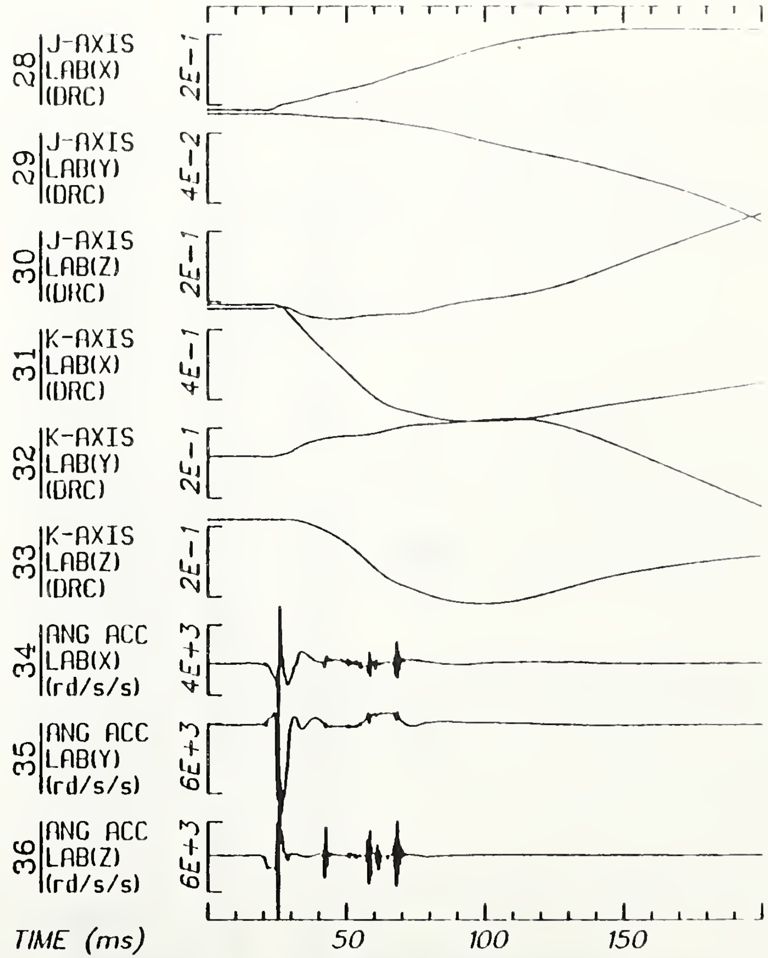

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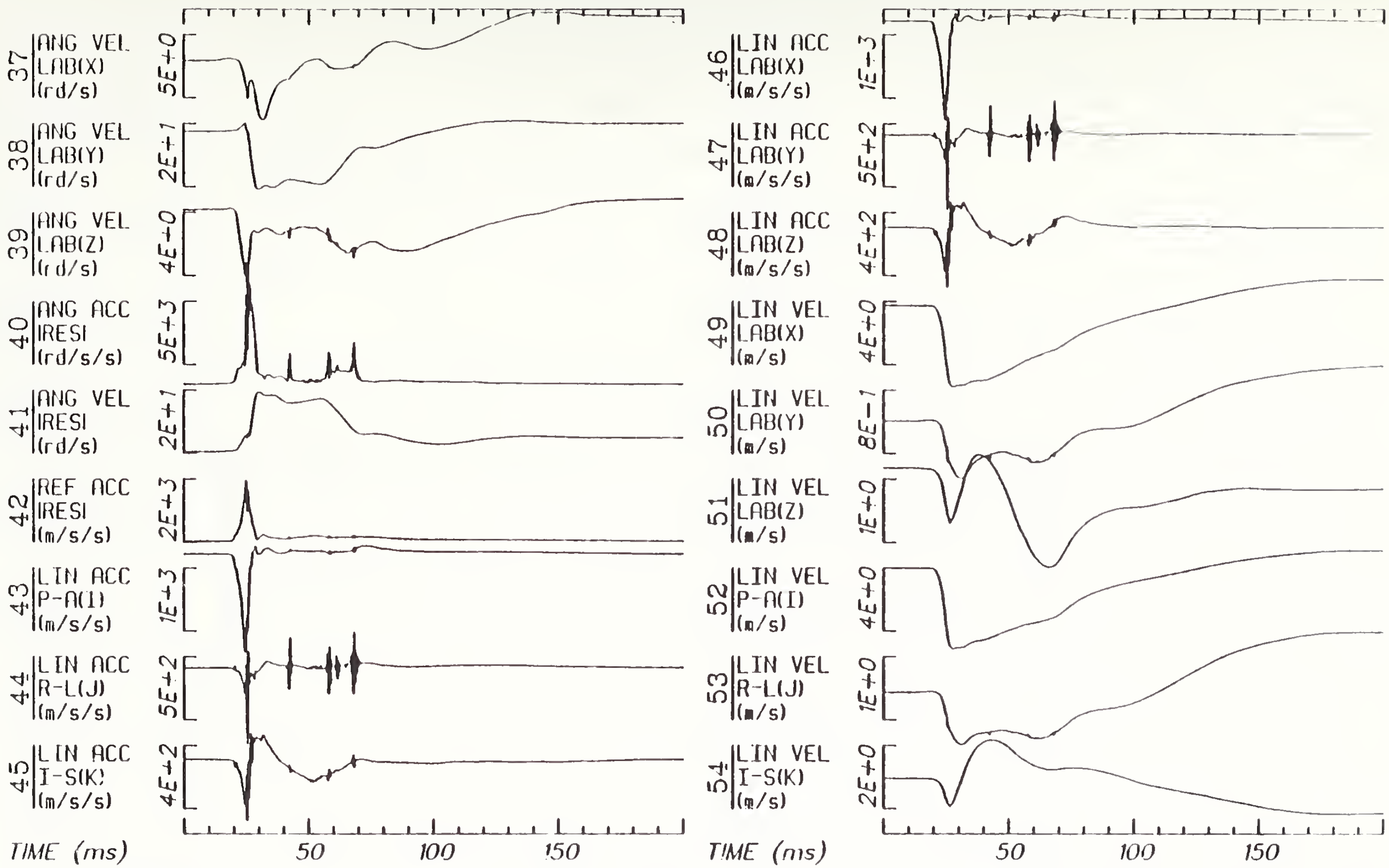

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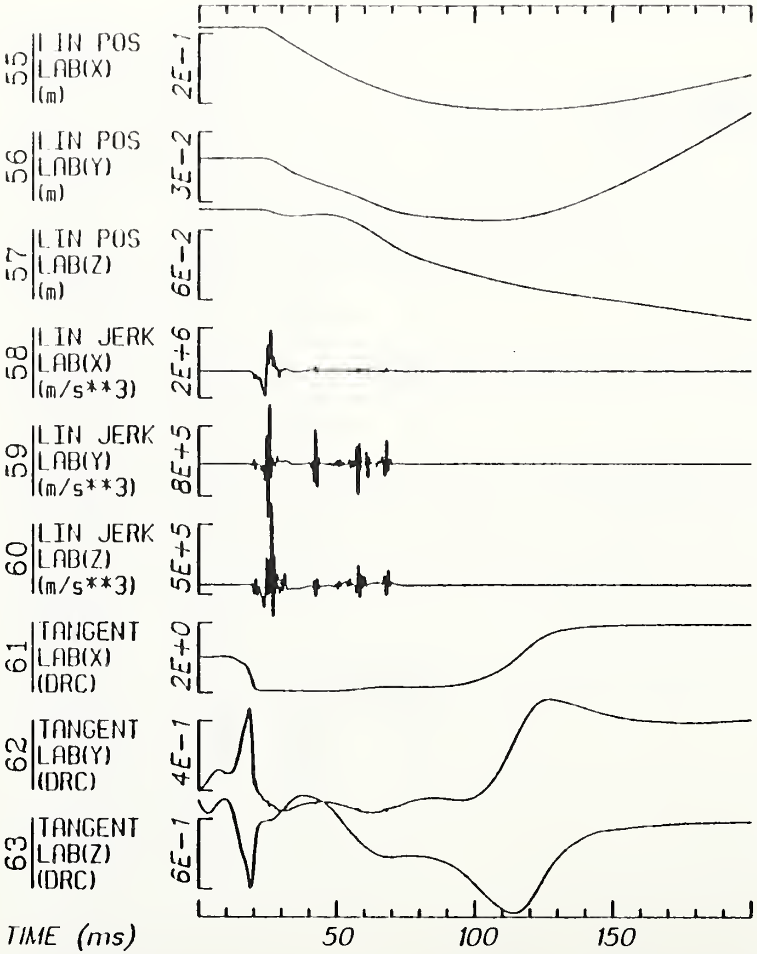

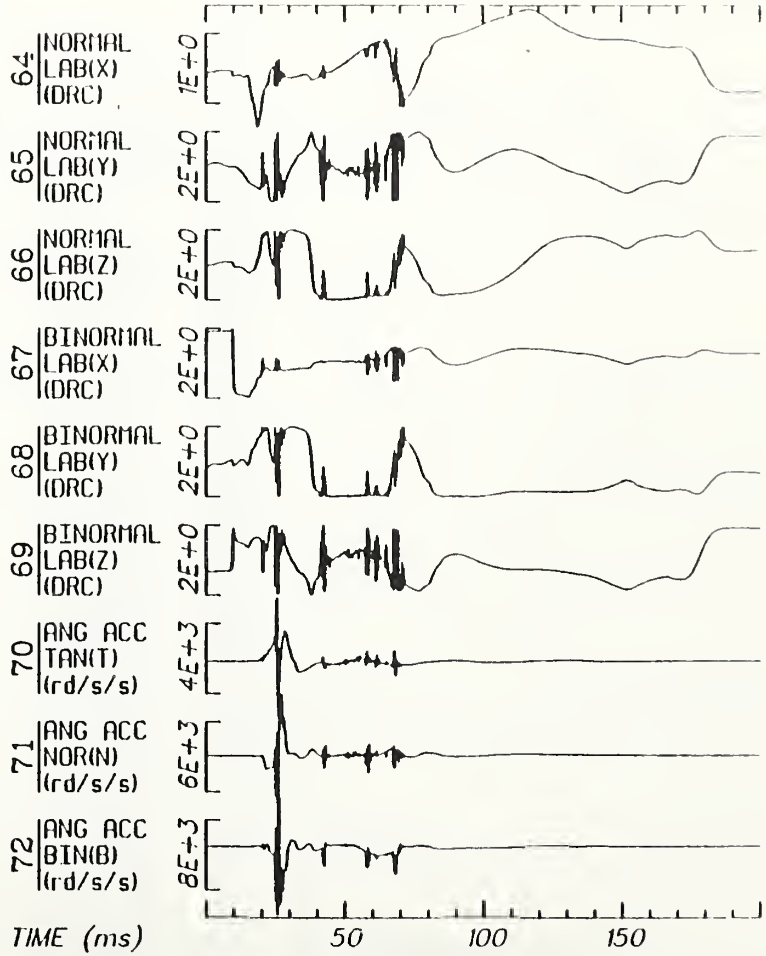

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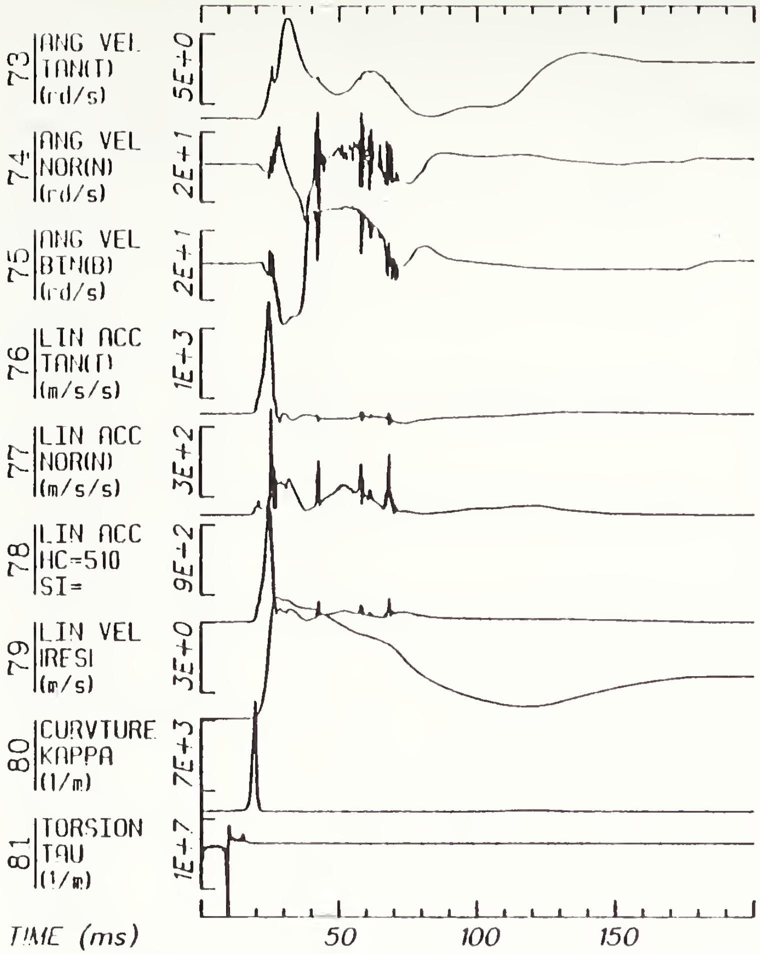

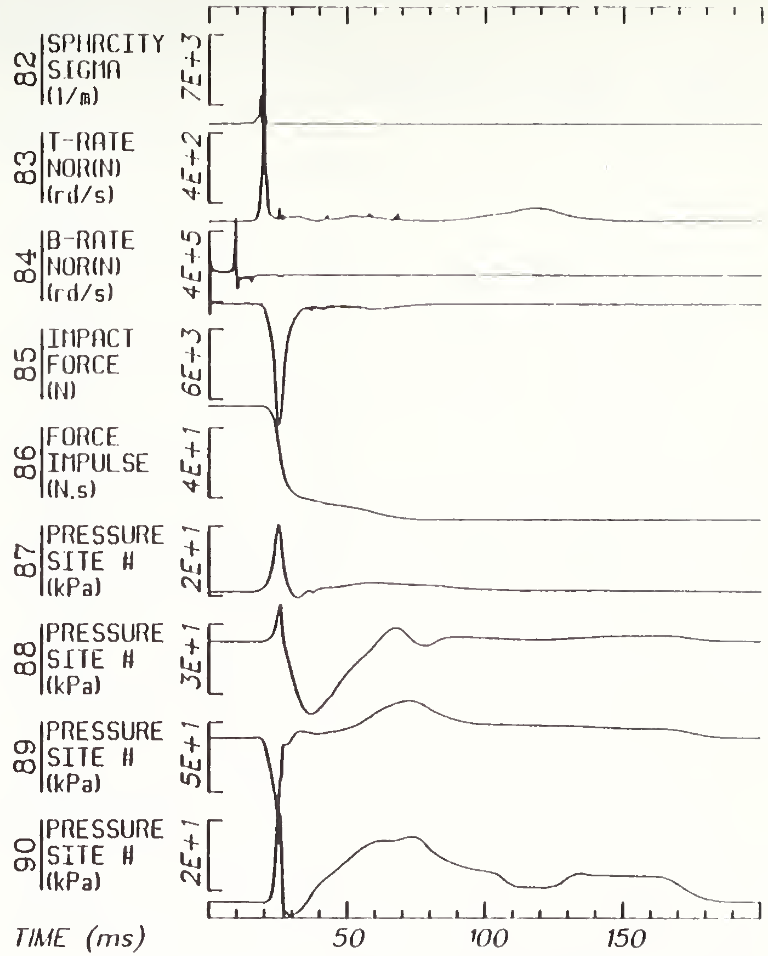

Run ID: 82E041 Disk: -HEAD File: 1 Date: MAR 11, 1985 Sheet: 5

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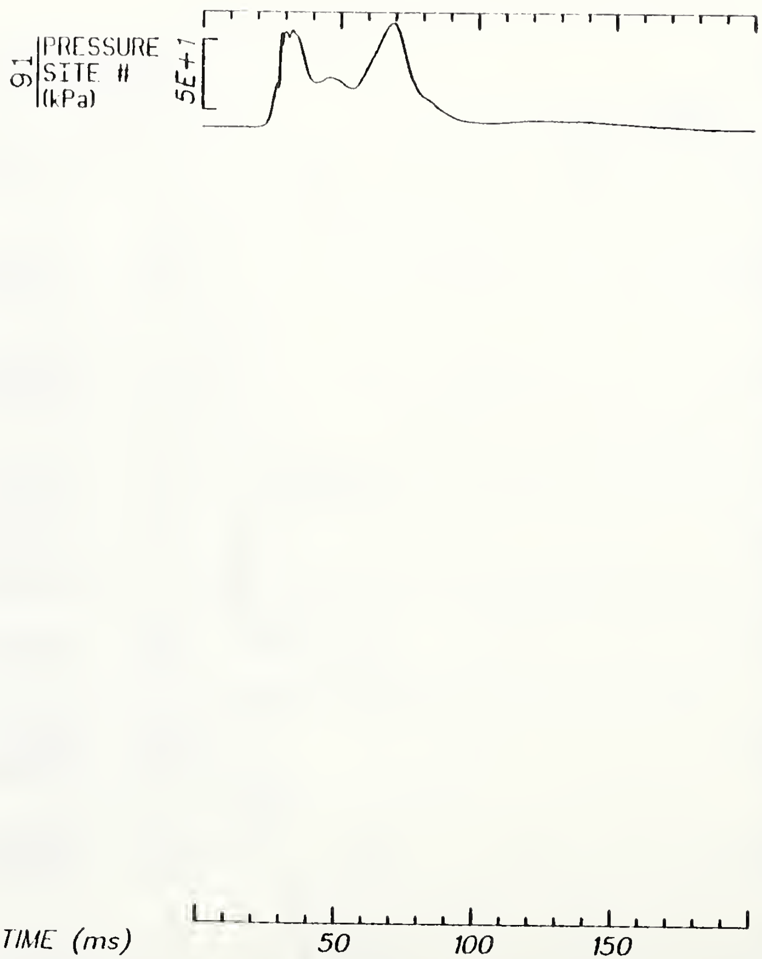

TIME (ms)

Run ID: 82E041   Disk: –HEAD   File: 1   Date: MAR 11, 1985   Sheet: 6

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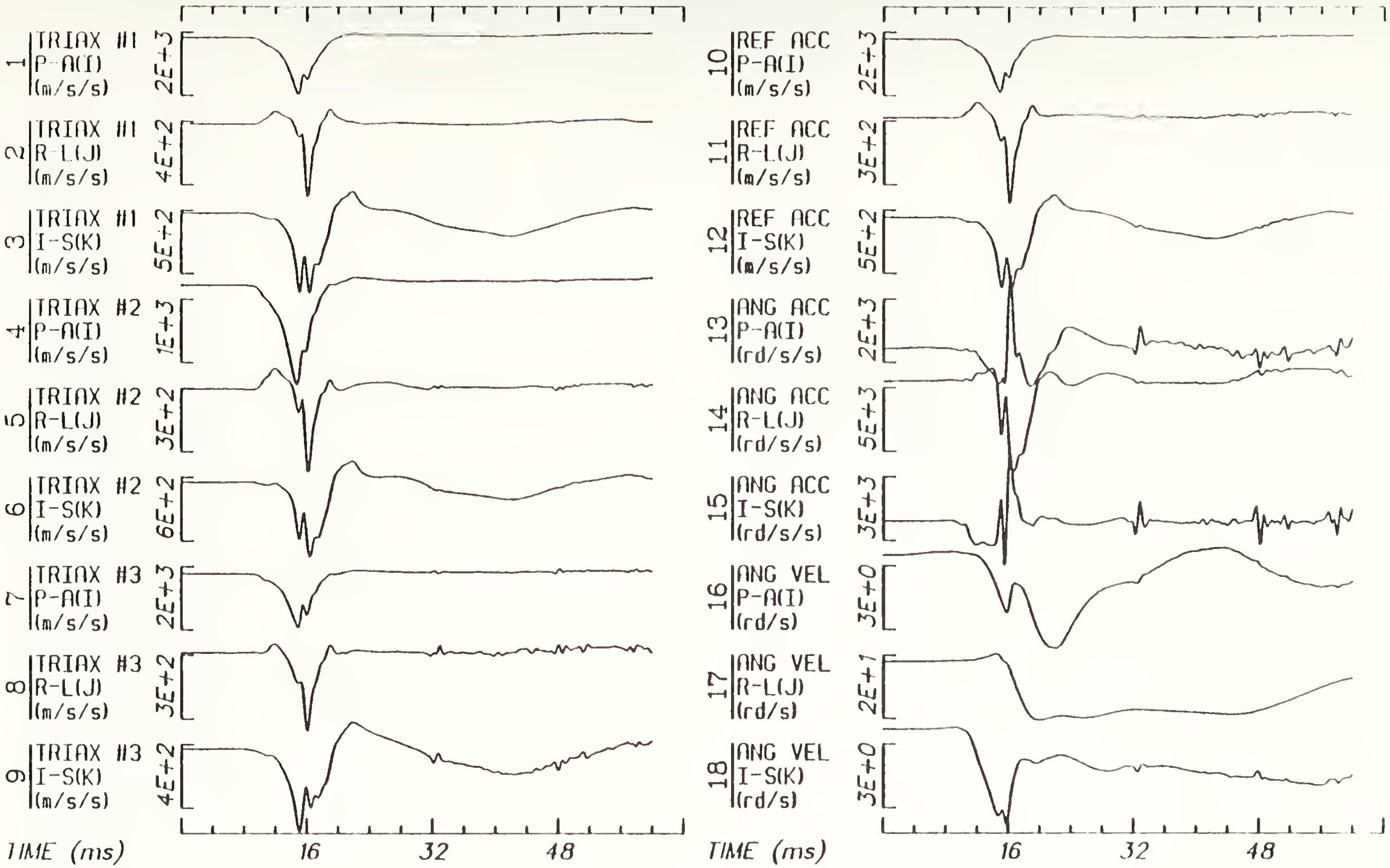

Run ID: 82E041 Disk: E041.3D. File: 1 Date: MAR 7, 1985 Sheet: 1

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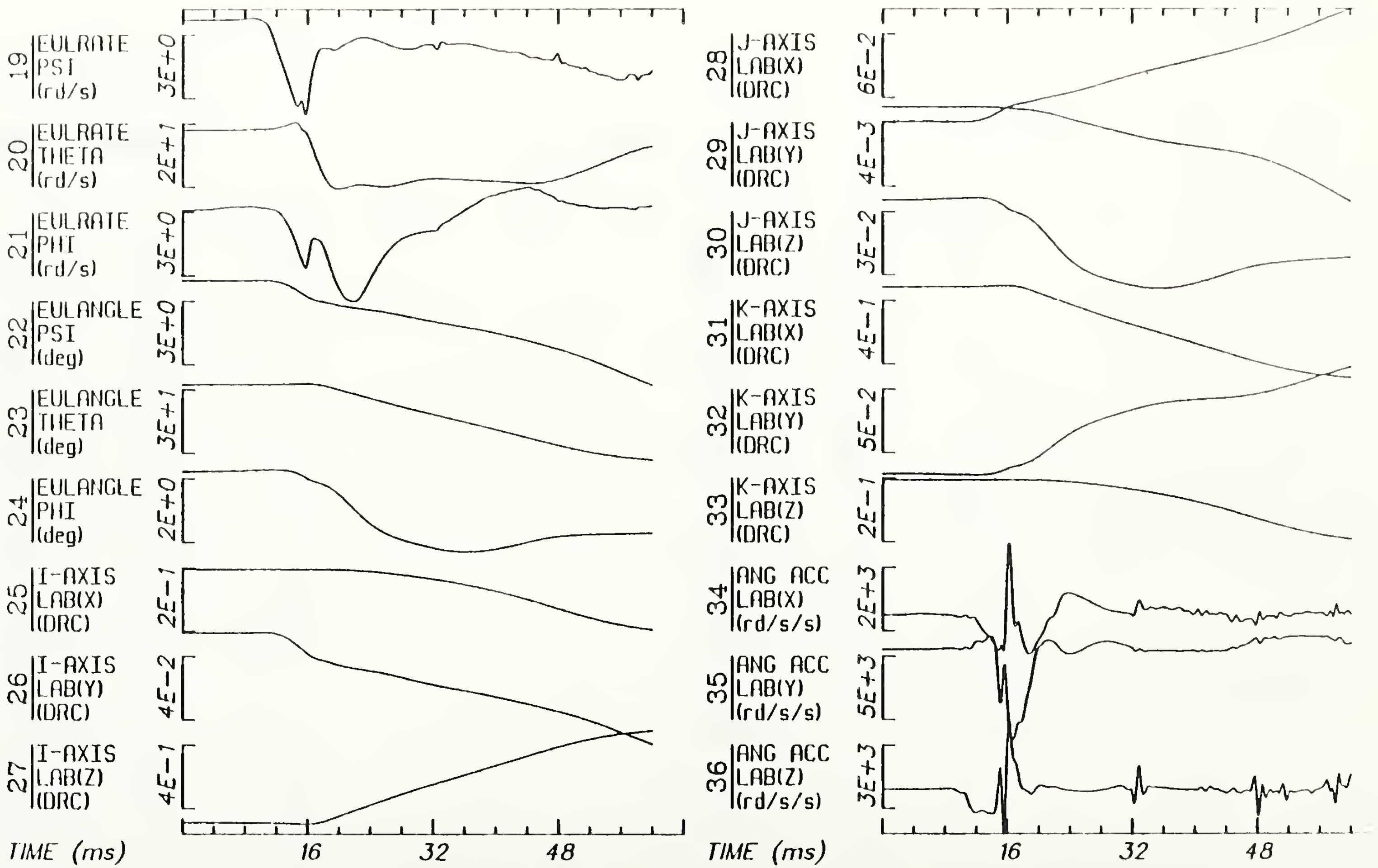

Run ID: 82E041 Disk: E041.3D. File: 1 Date: MAR 7, 1985 Sheet: 2

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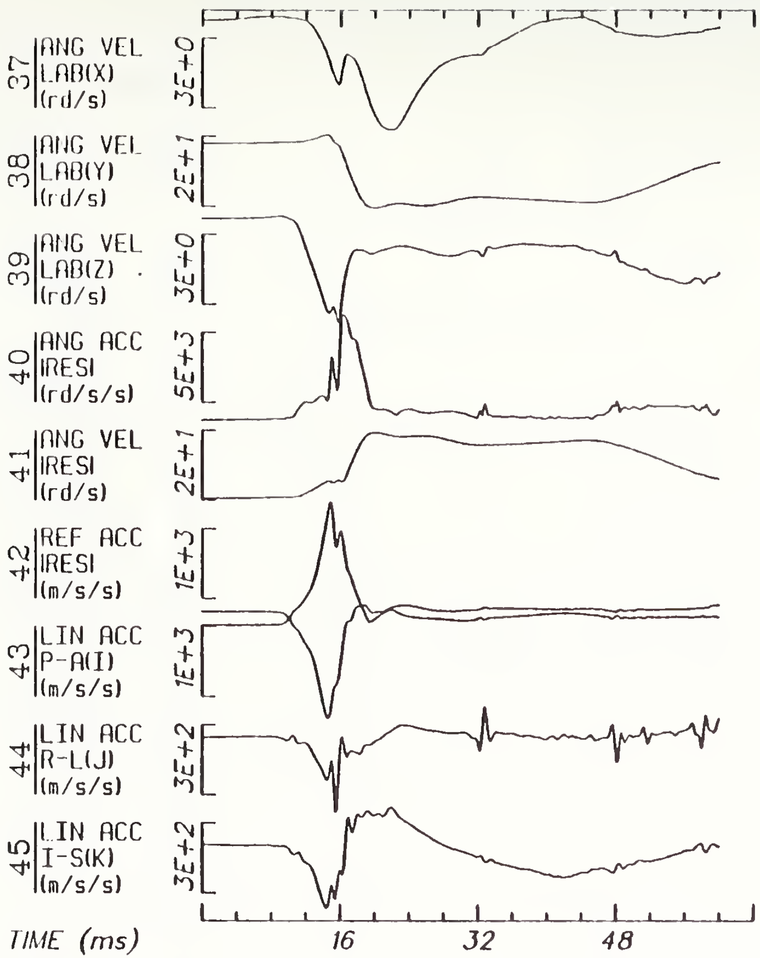

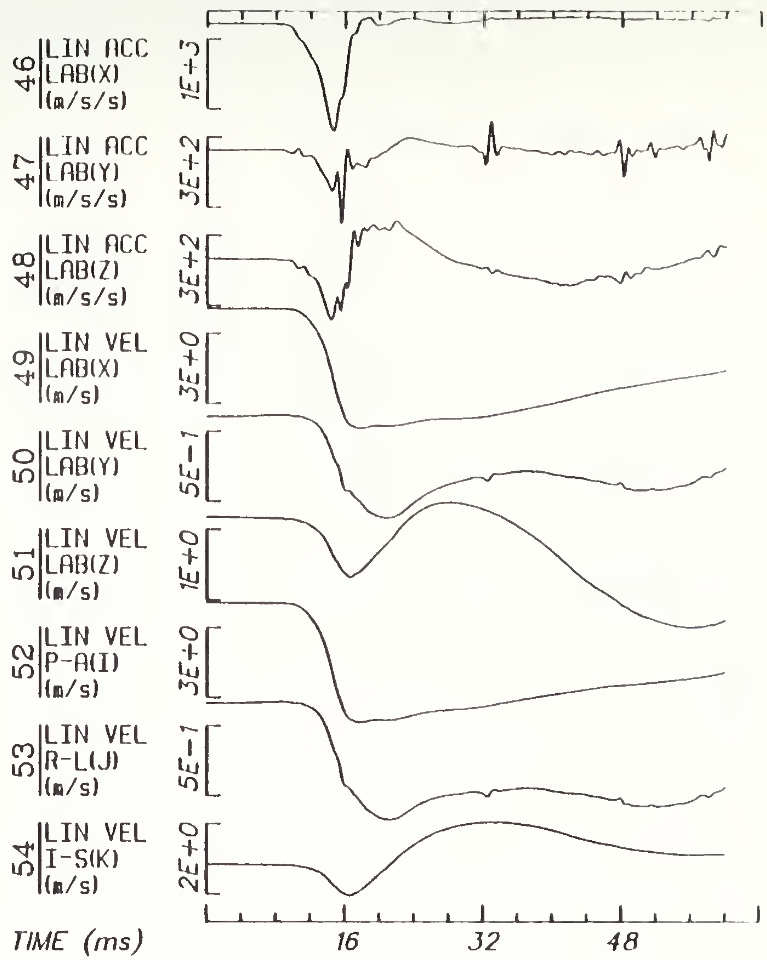

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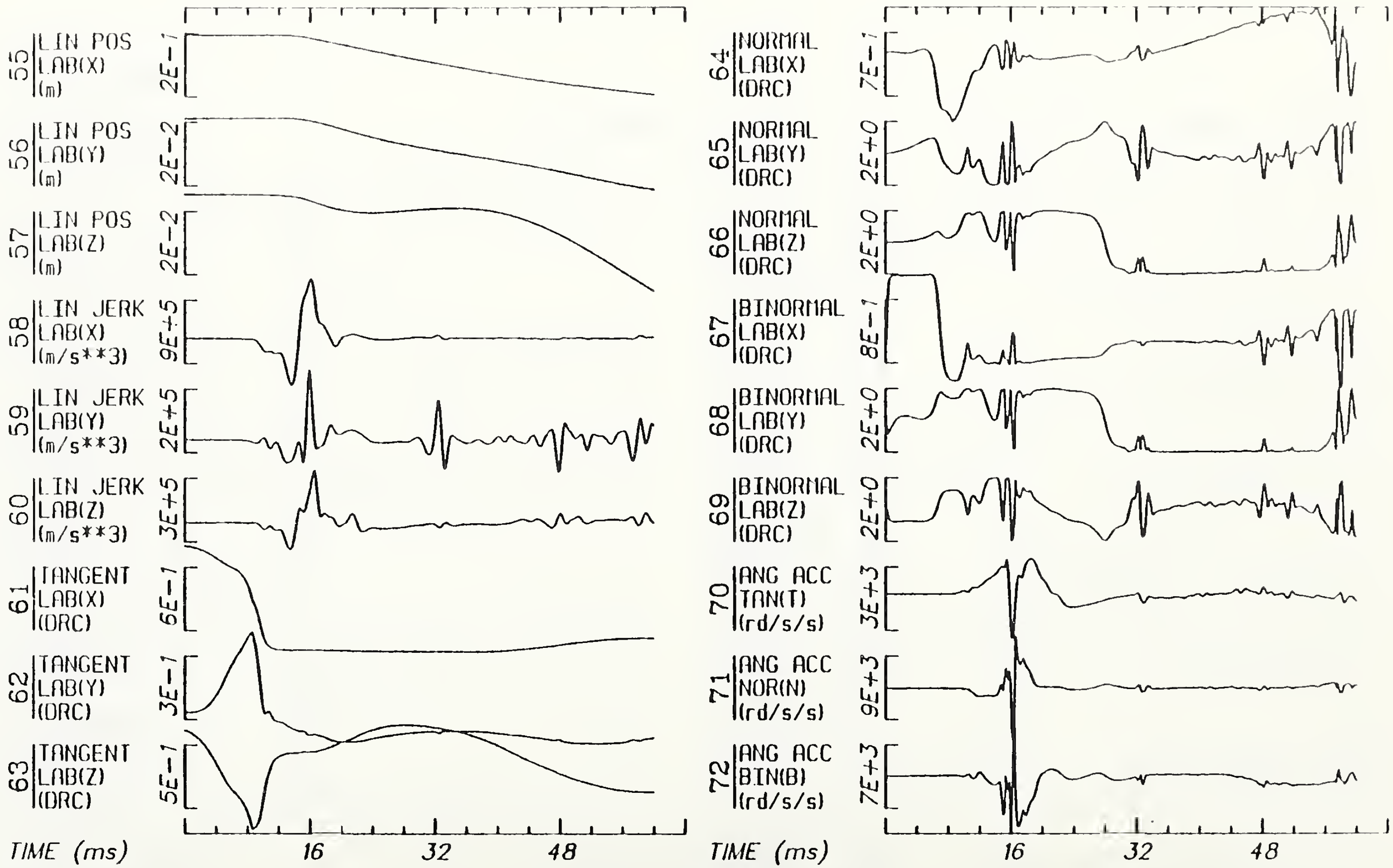

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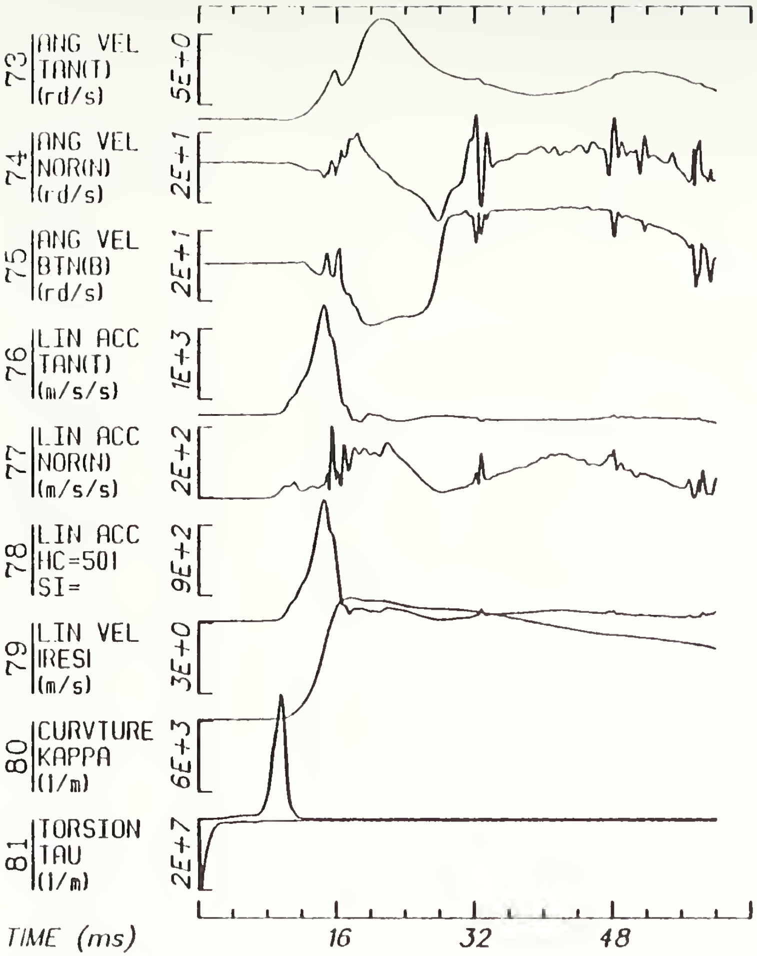

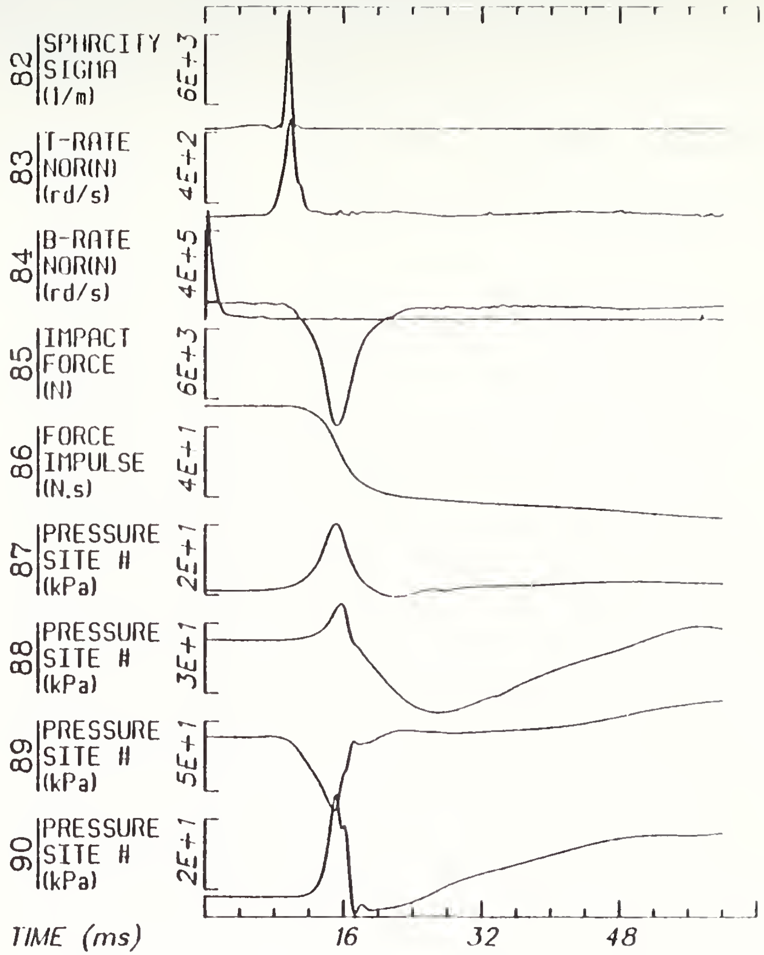

Run ID: 82E041 Disk: E041.3D. File: 1 Date: MAR 7, 1985 Sheet: 5

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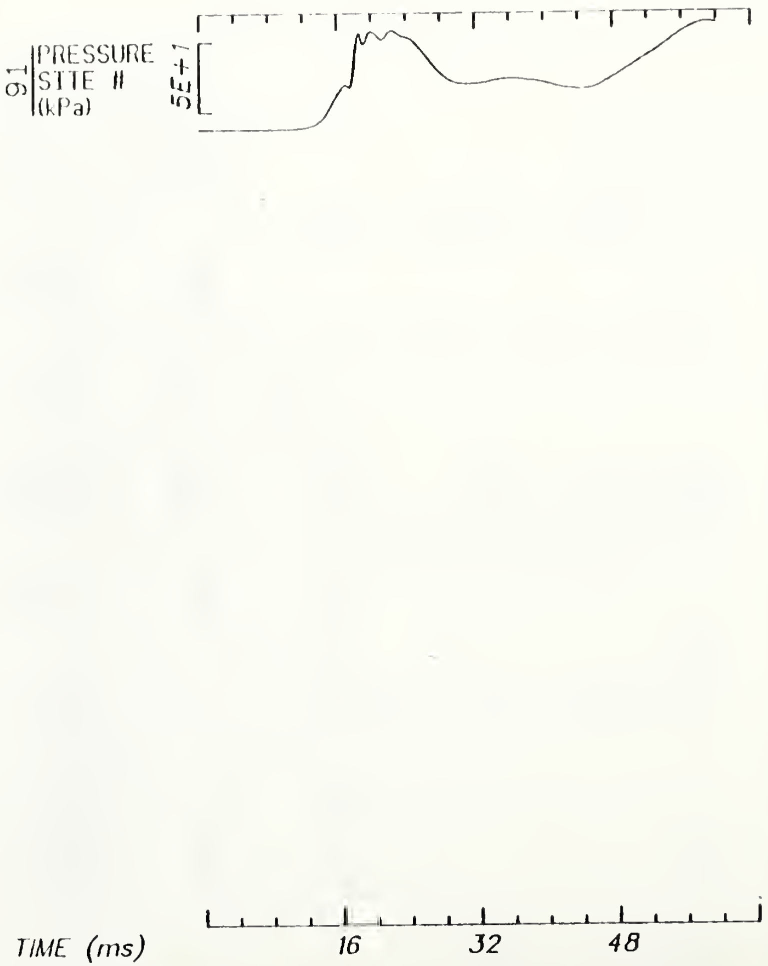

Run ID: 82E041 Disk: E041.3D. File: 1 Date: MAR 7, 1985 Sheet: 6

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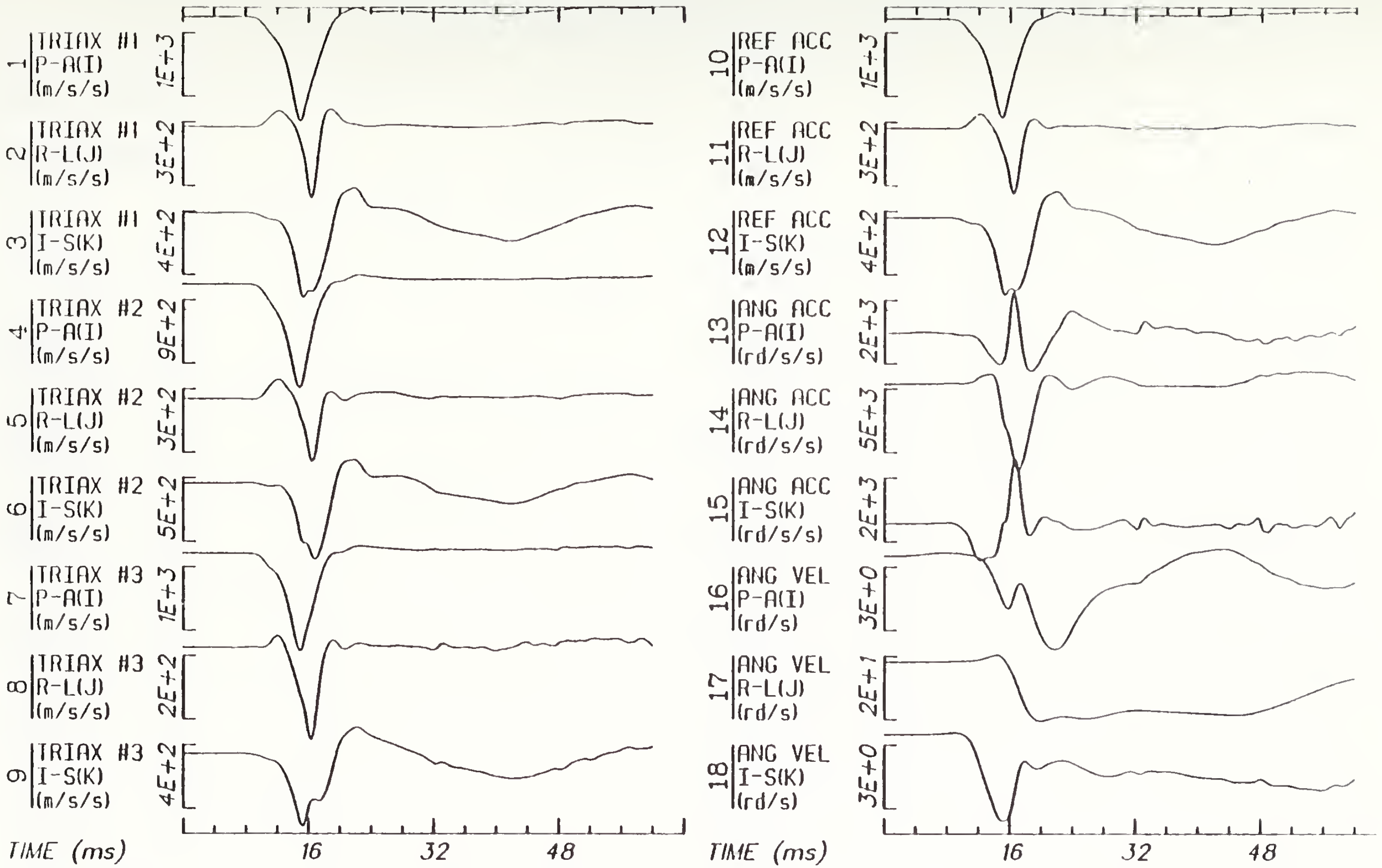

Run ID: 82E041 Disk: E041.3D. File: 1 Date: MAR 7, 1985 Sheet: 1

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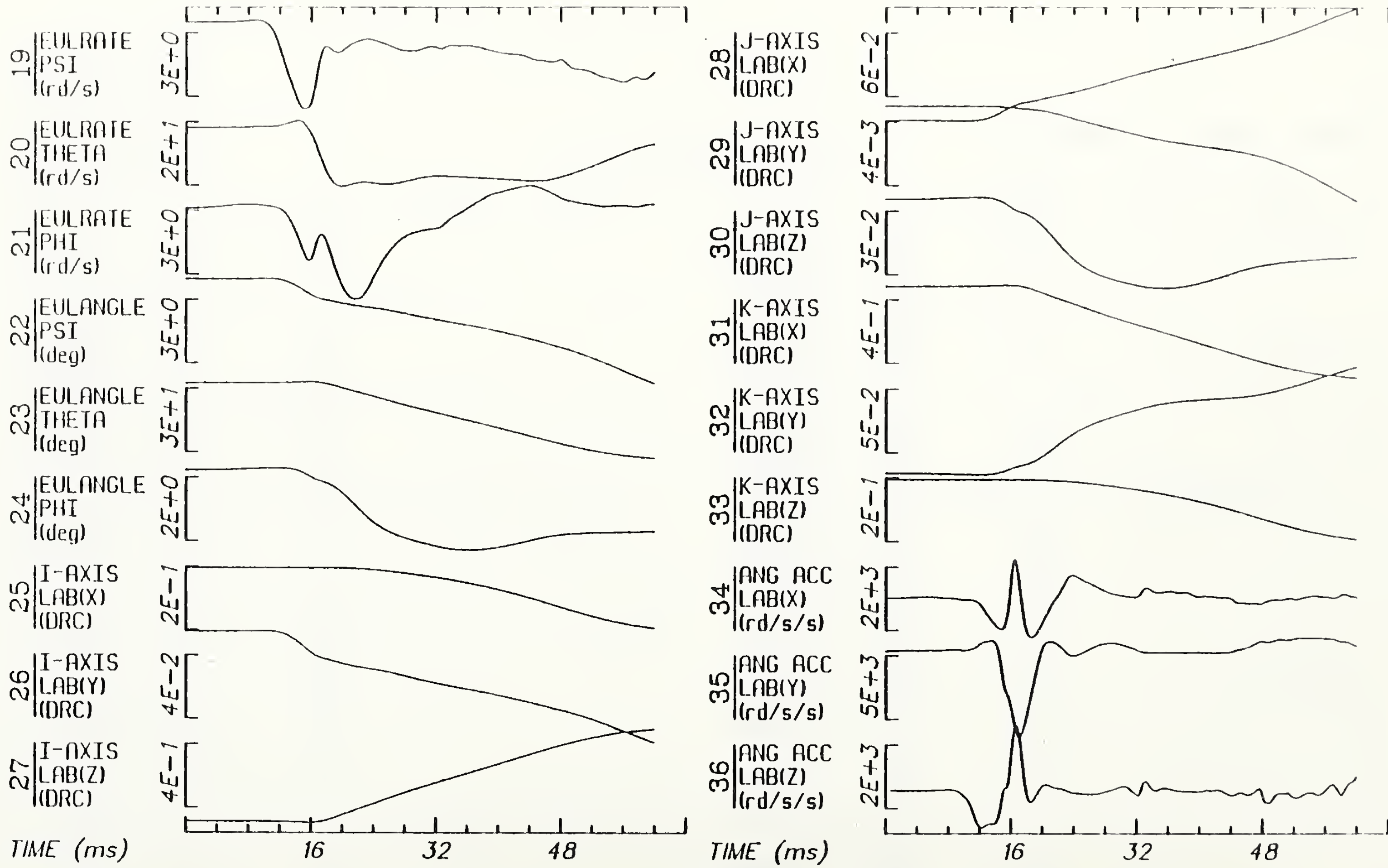

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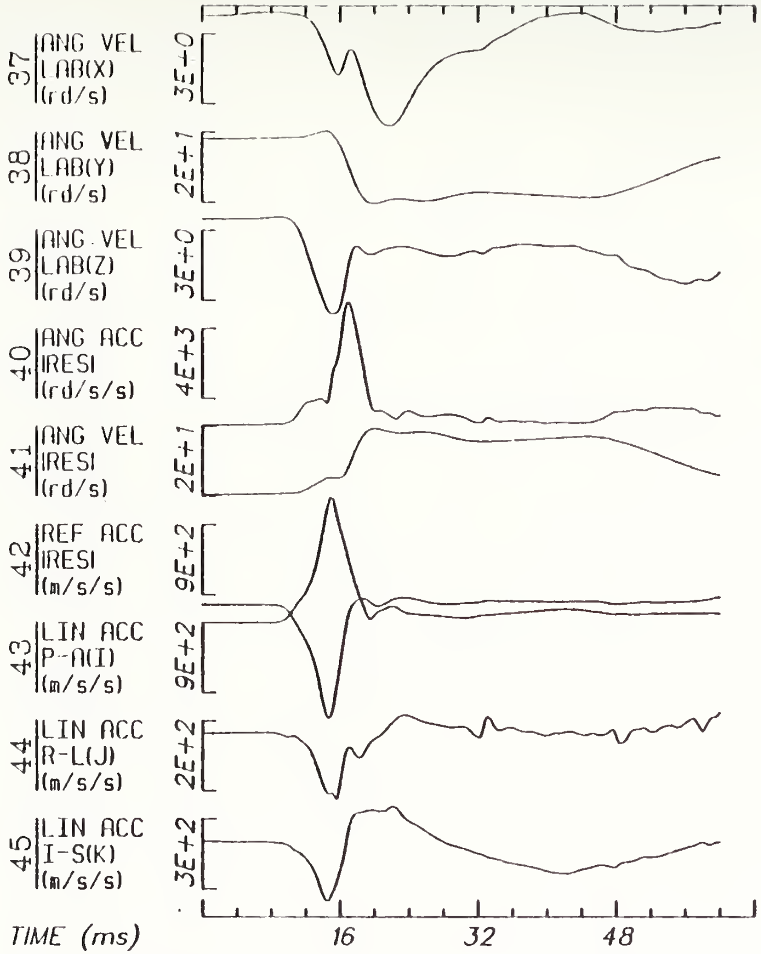

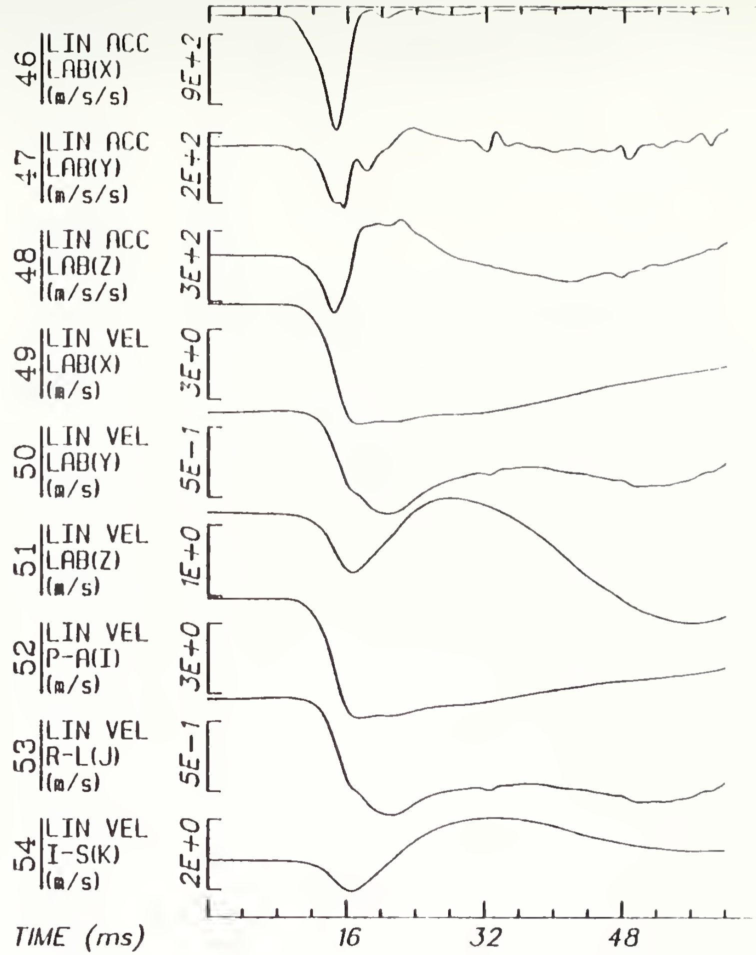

Run ID: 82E041 Disk: E041.3D. File: 1 Date: MAR 7, 1985 Sheet: 3

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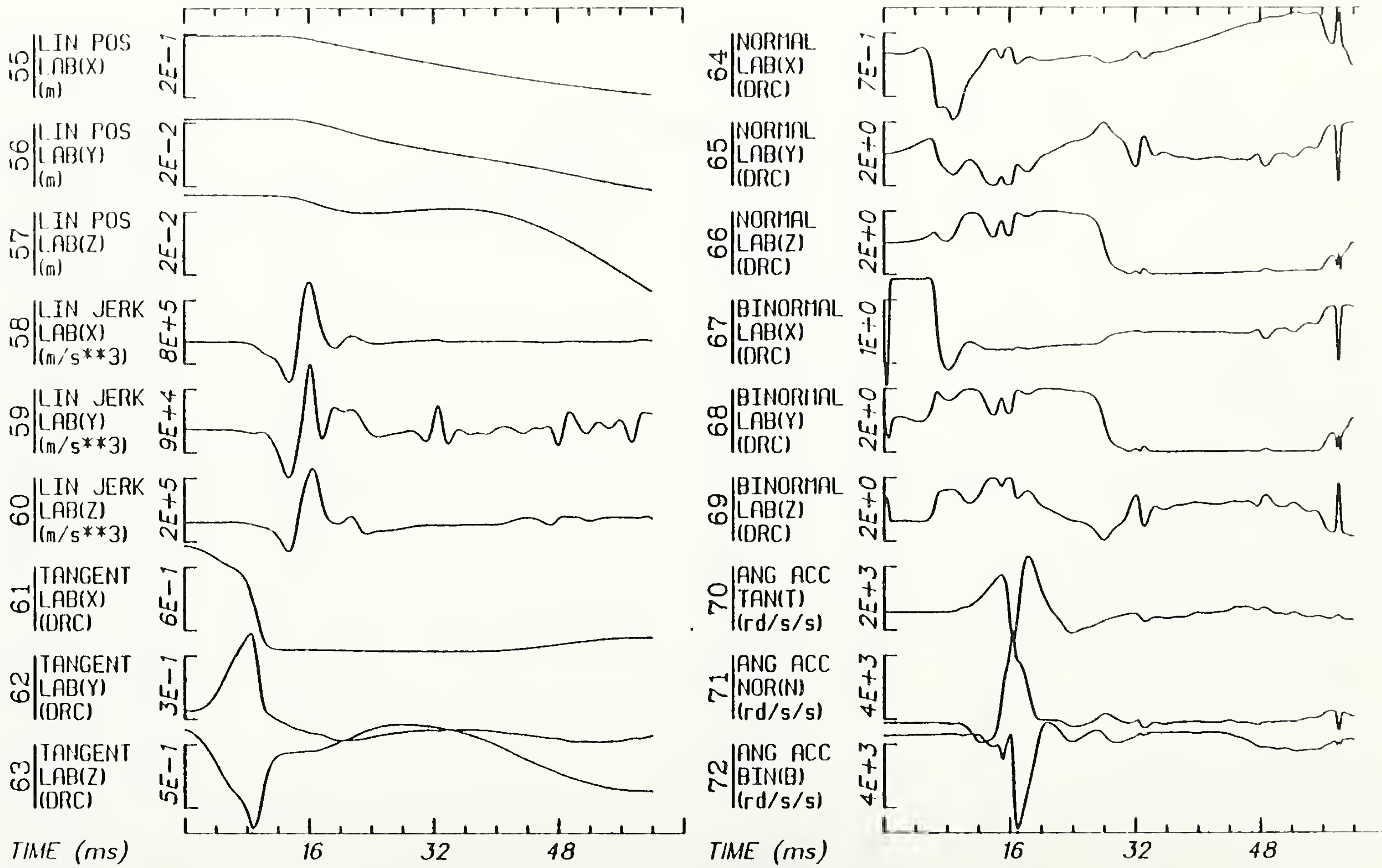

Run ID: 82E041 Disk: E041.3D. File: 1 Date: MAR 7, 1985 Sheet: 4

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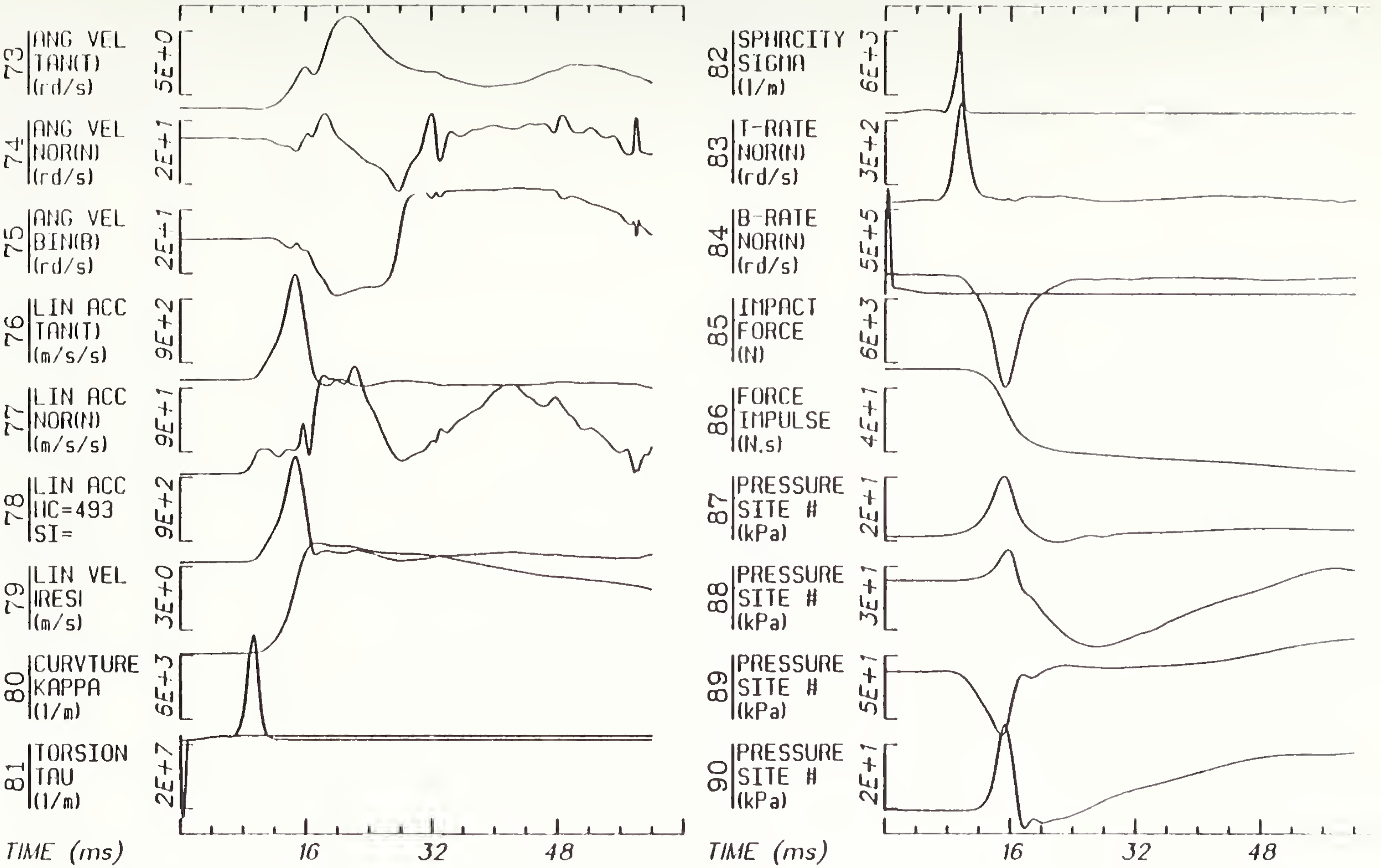

Run ID: 82E041 Disk: E041.3D. File: 1 Date: MAR 7, 1985 Sheet: 5

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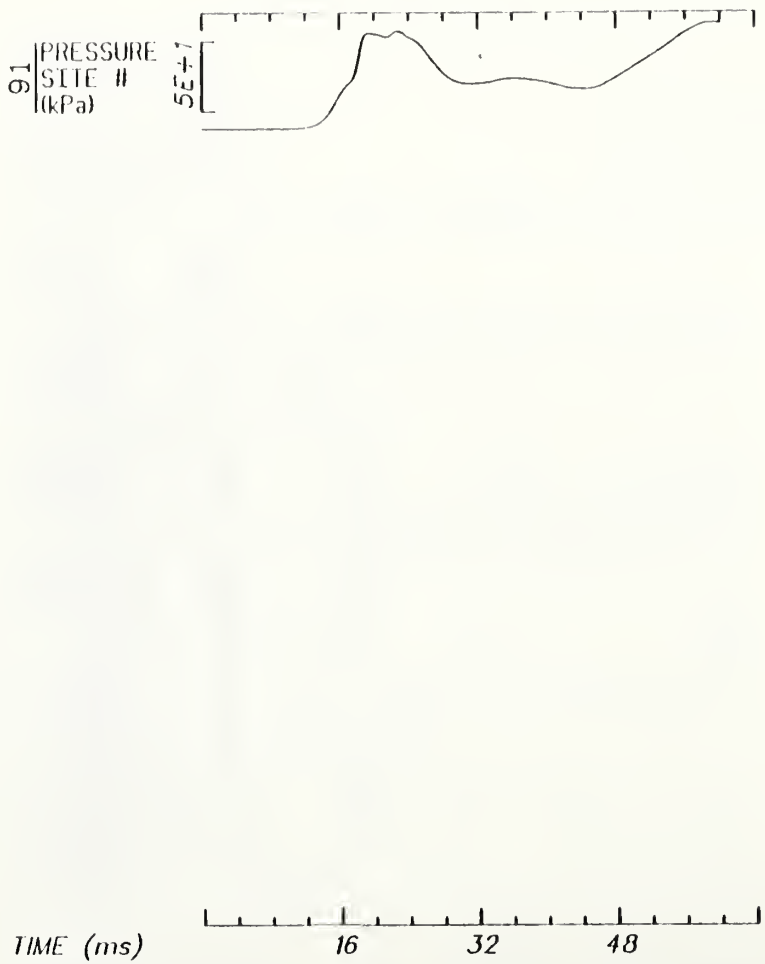


Run ID: 82E041

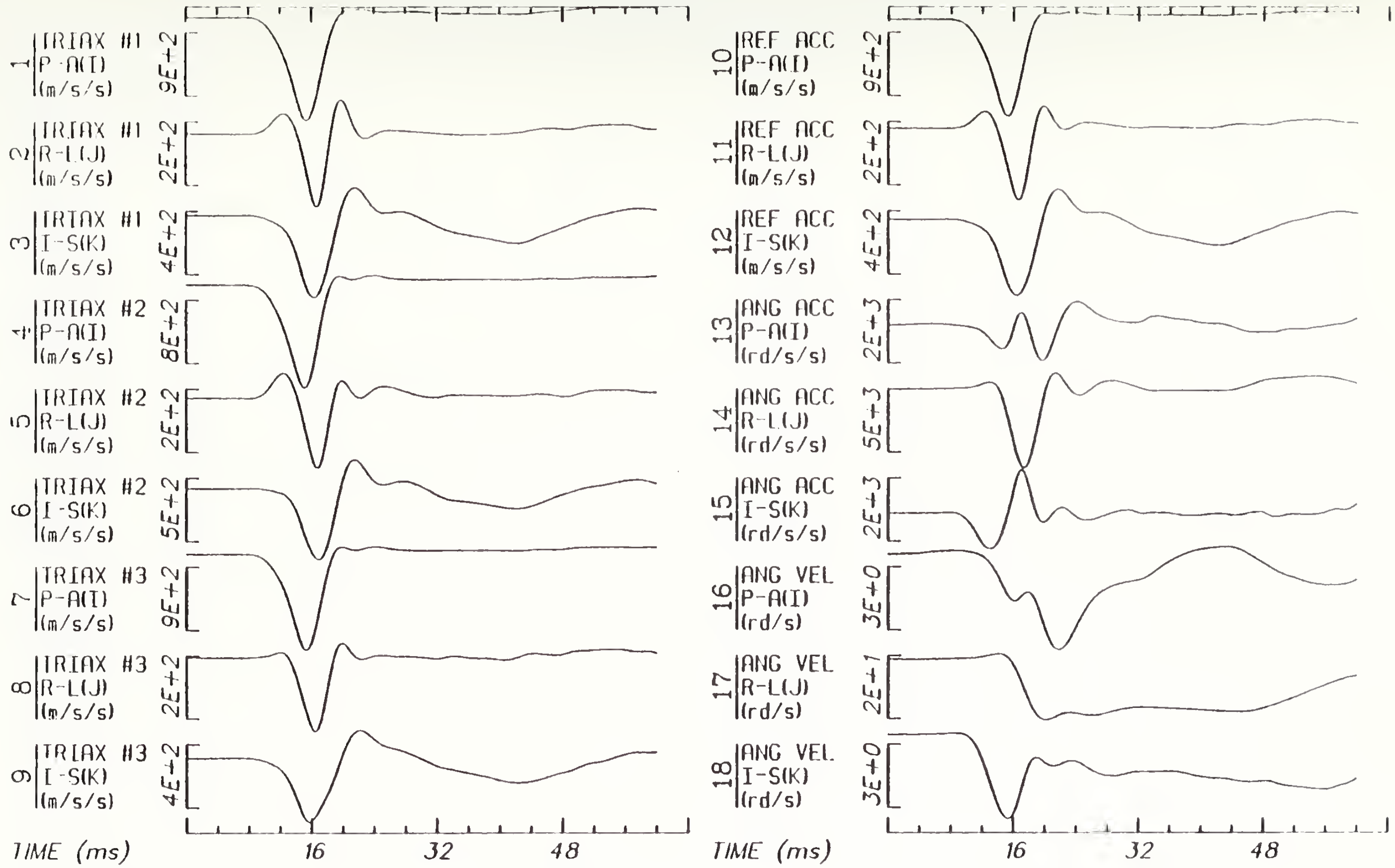
Disk: E041.3D.

File: 1

Date: MAR 7, 1985

Sheet: 6

Filter: 400*4C



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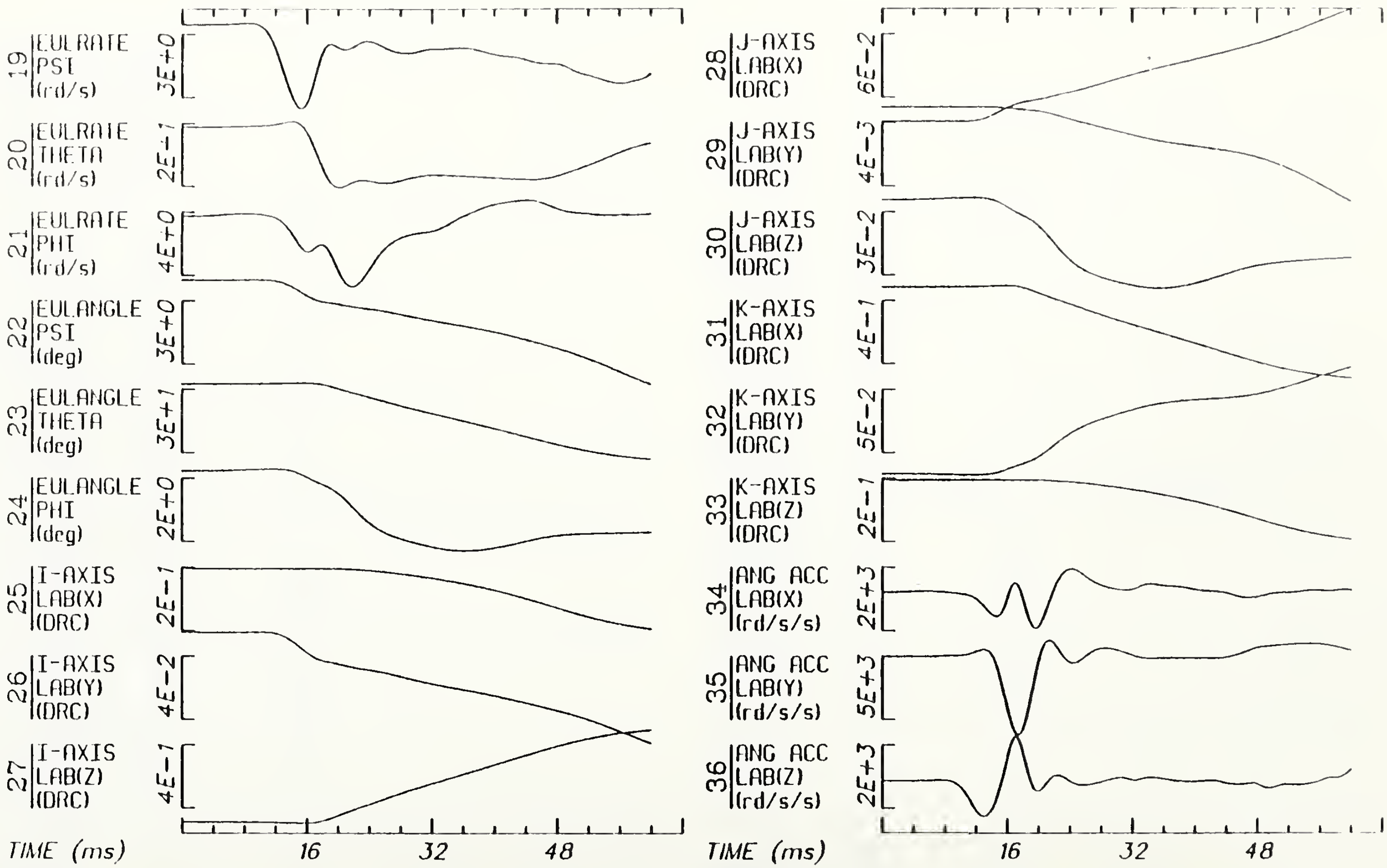

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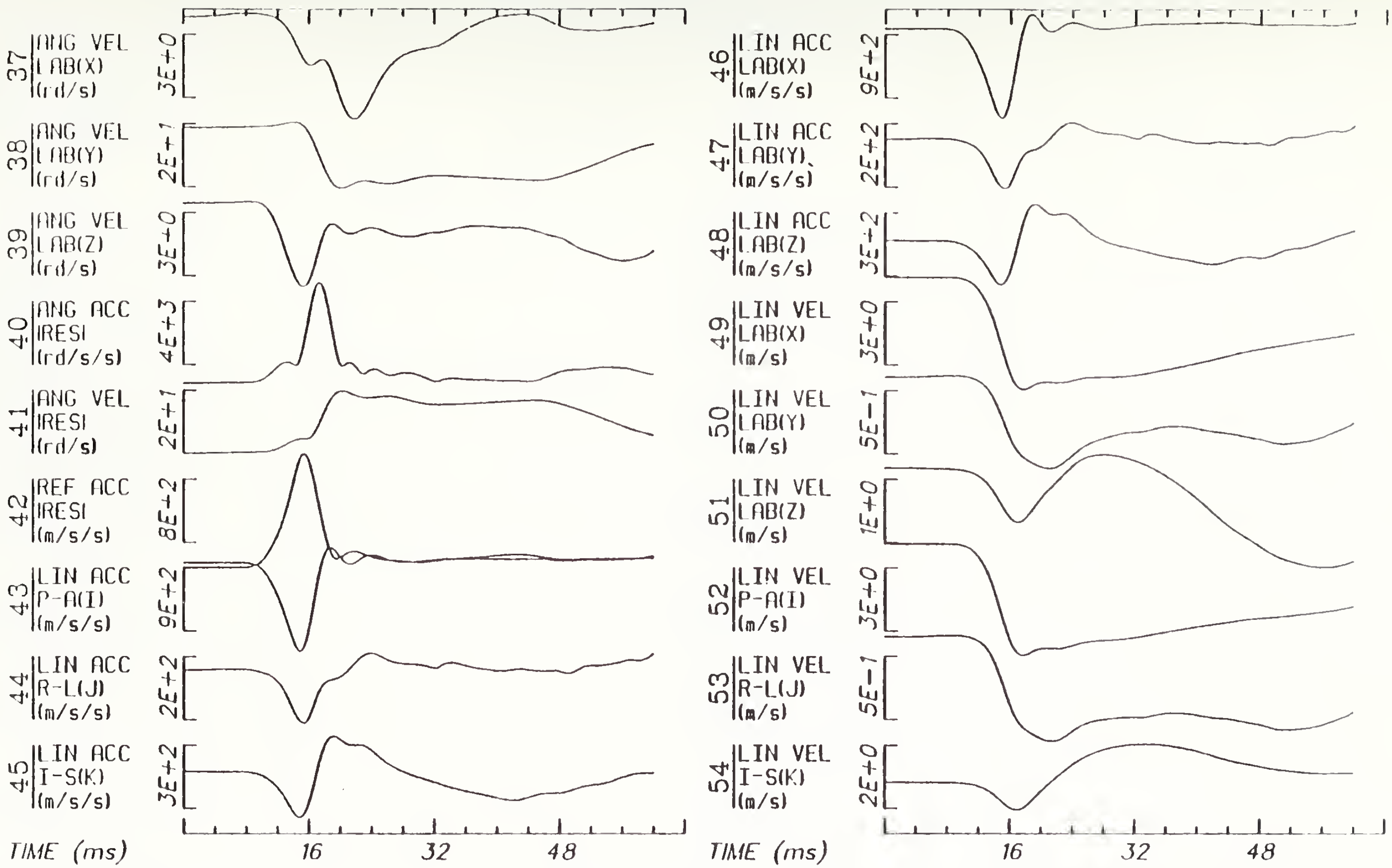

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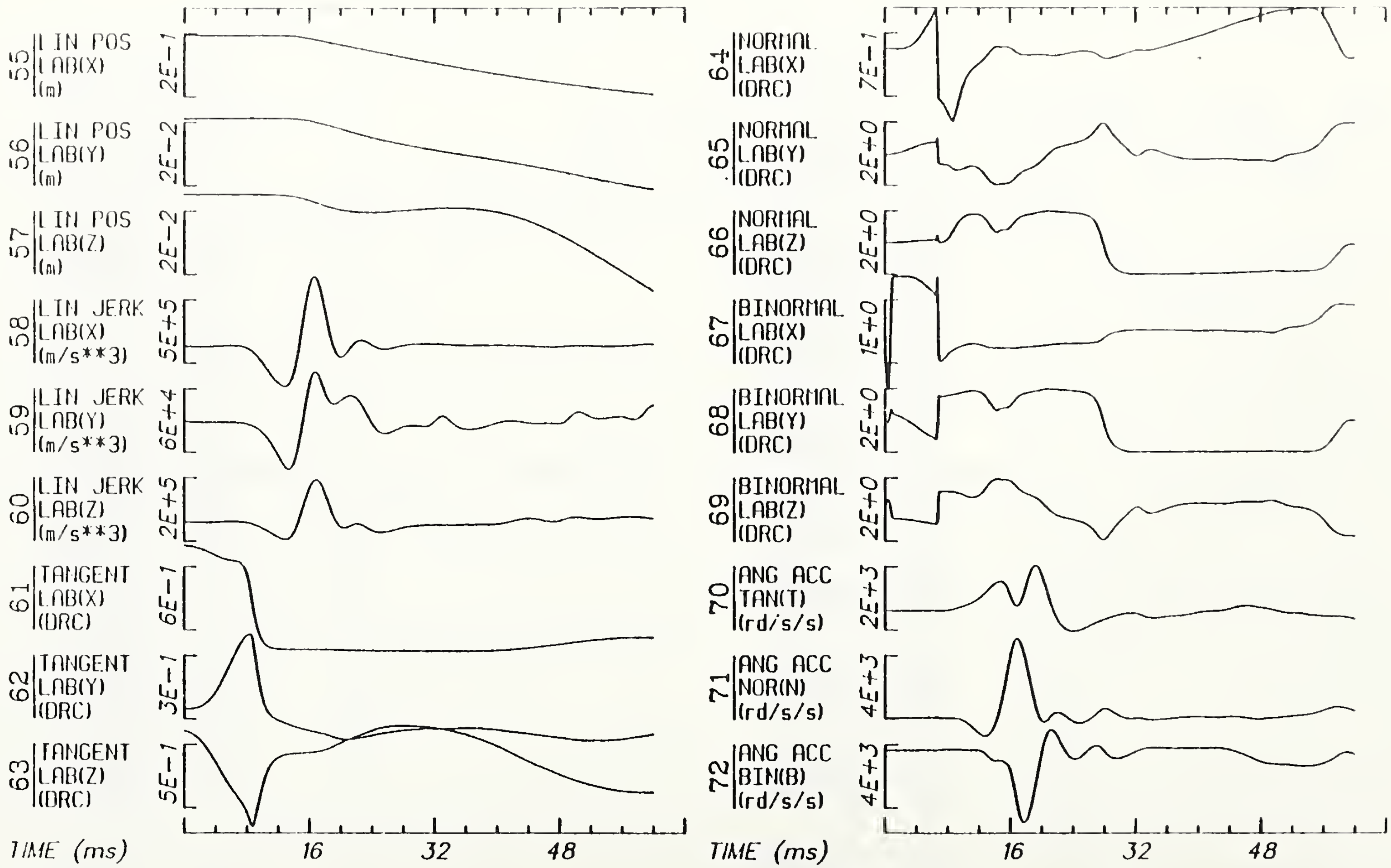

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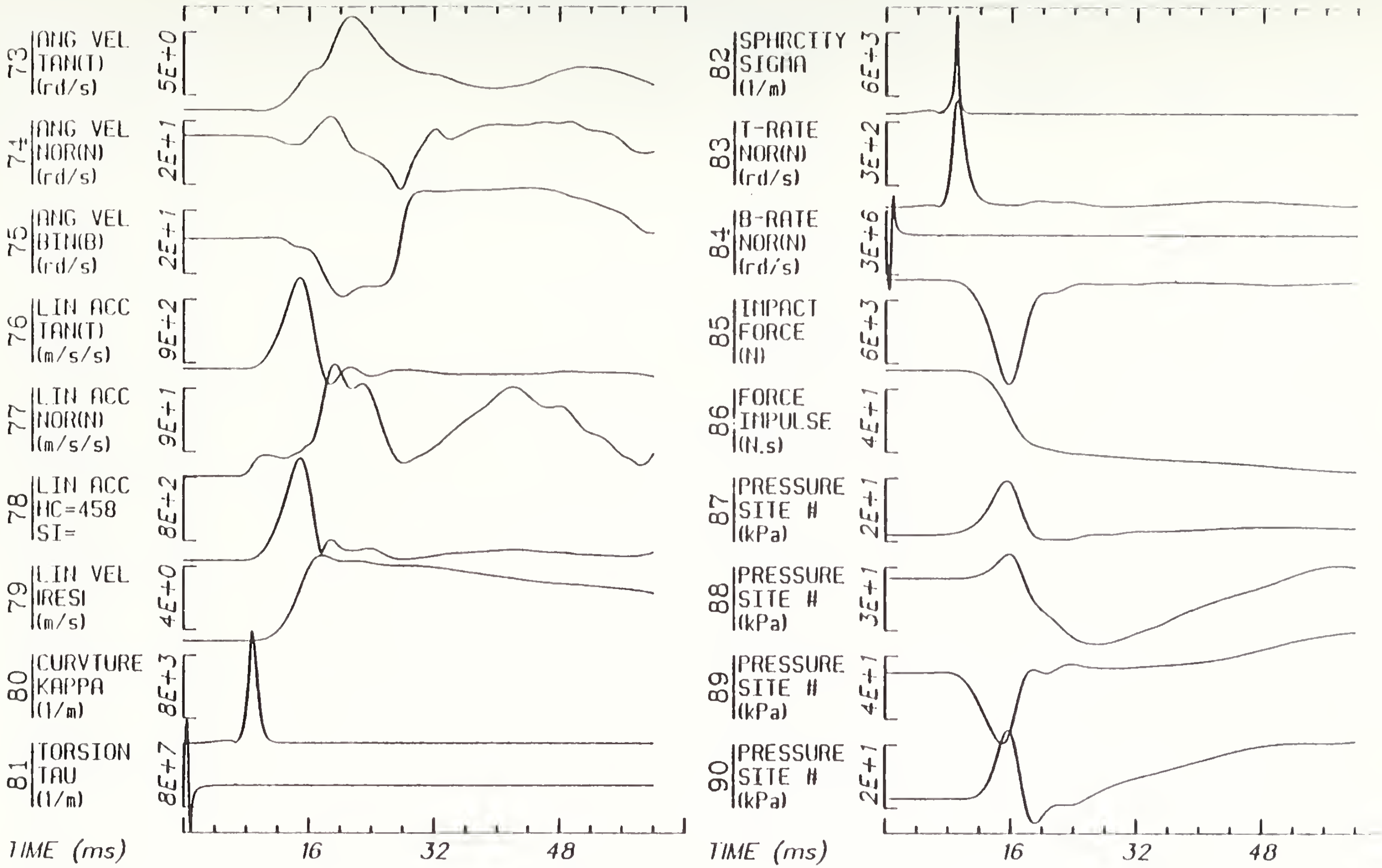

Run ID: 82E041 Disk: E041.3D. File: 1 Date: MAR 7, 1985 Sheet: 5

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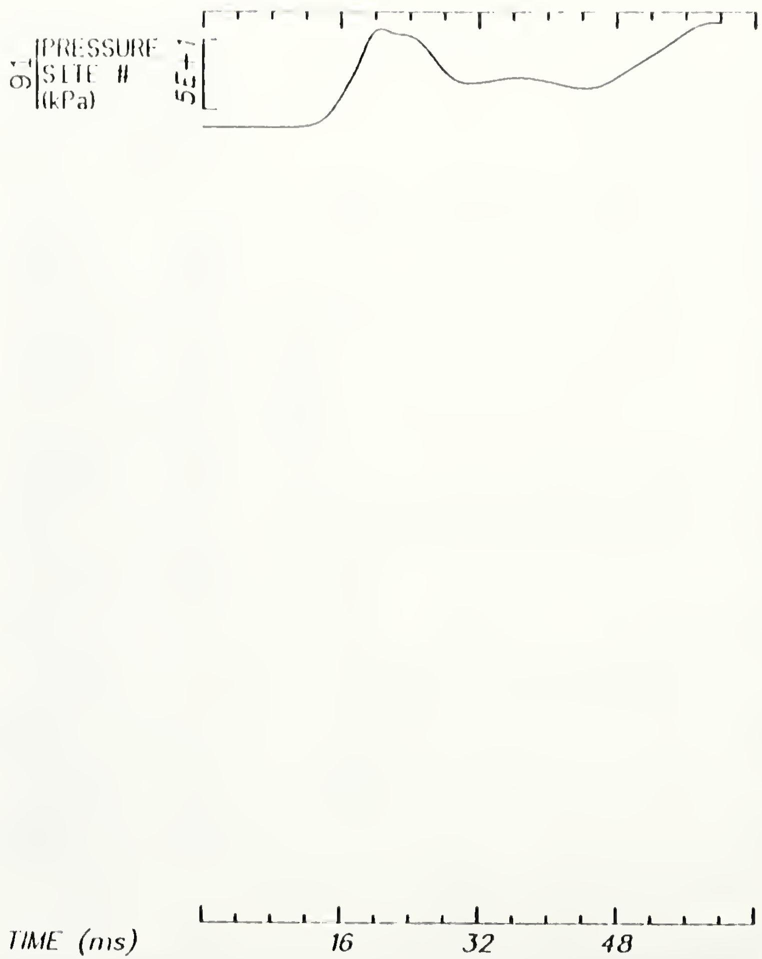

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Disk: E041.3D. File: 1

Date: MAR 7, 1985 Sheet: 6

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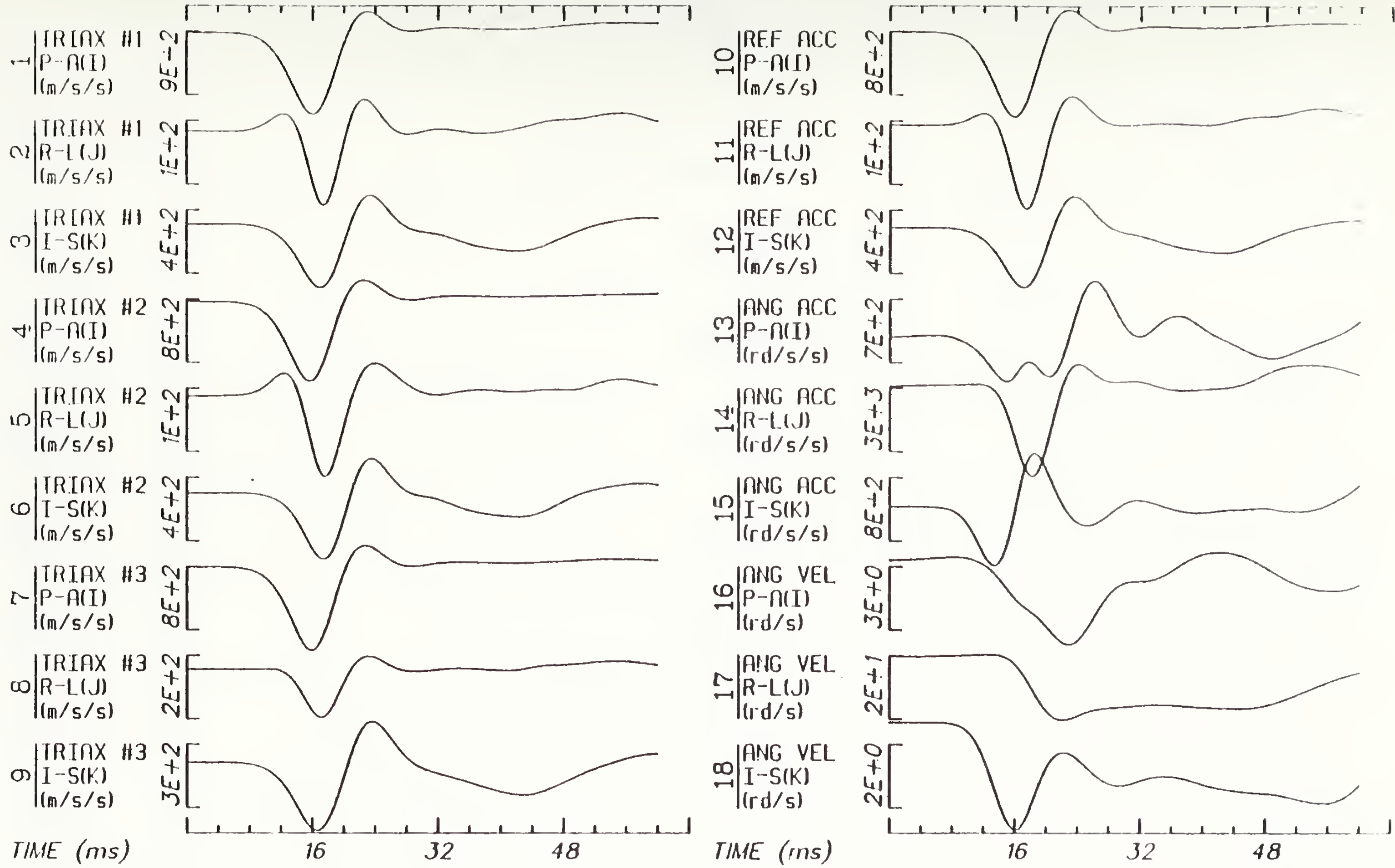
C40



Run ID: 82E041 Disk: E041.3D. File: 1 Date: MAR 7, 1985 Sheet: 1

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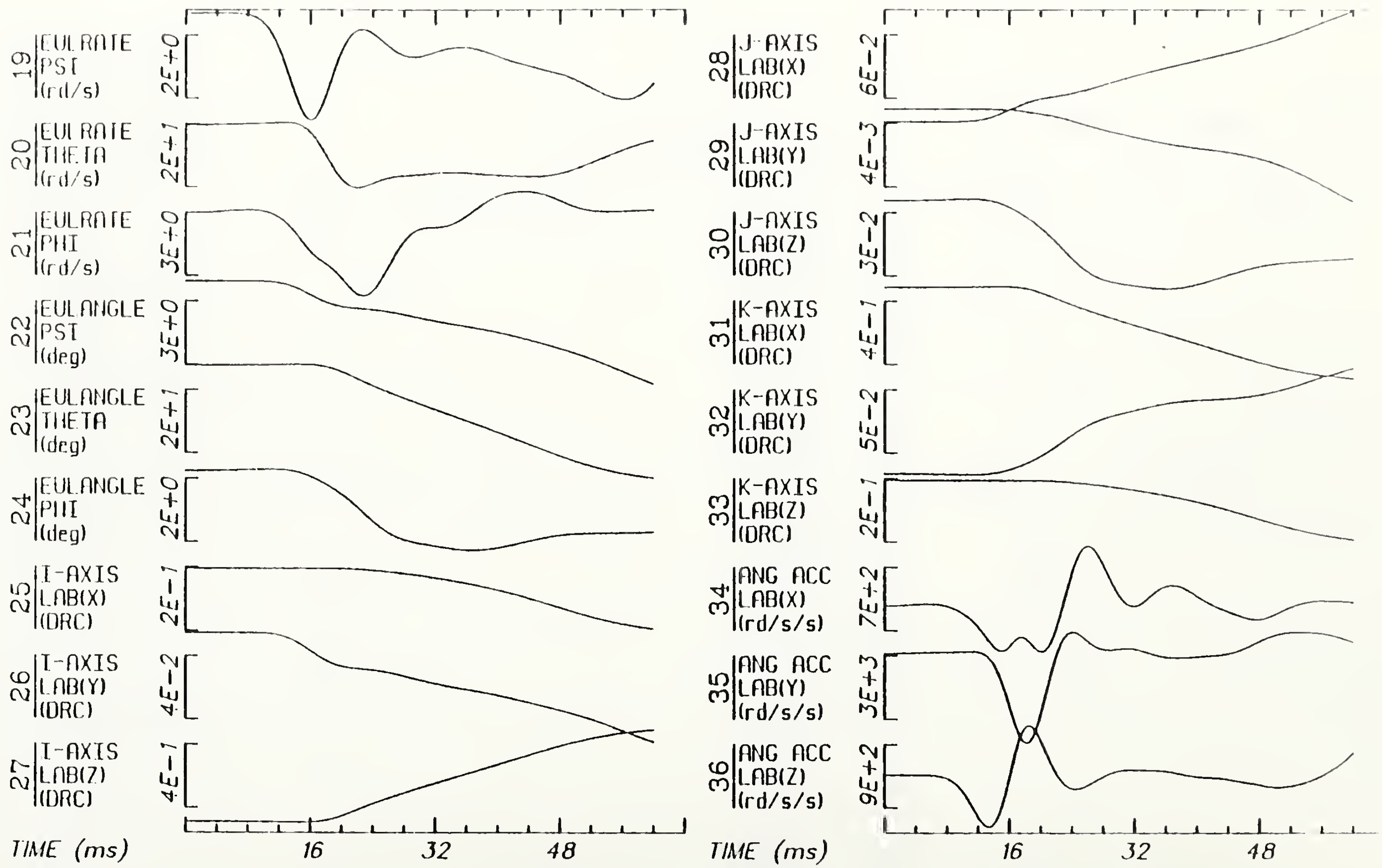

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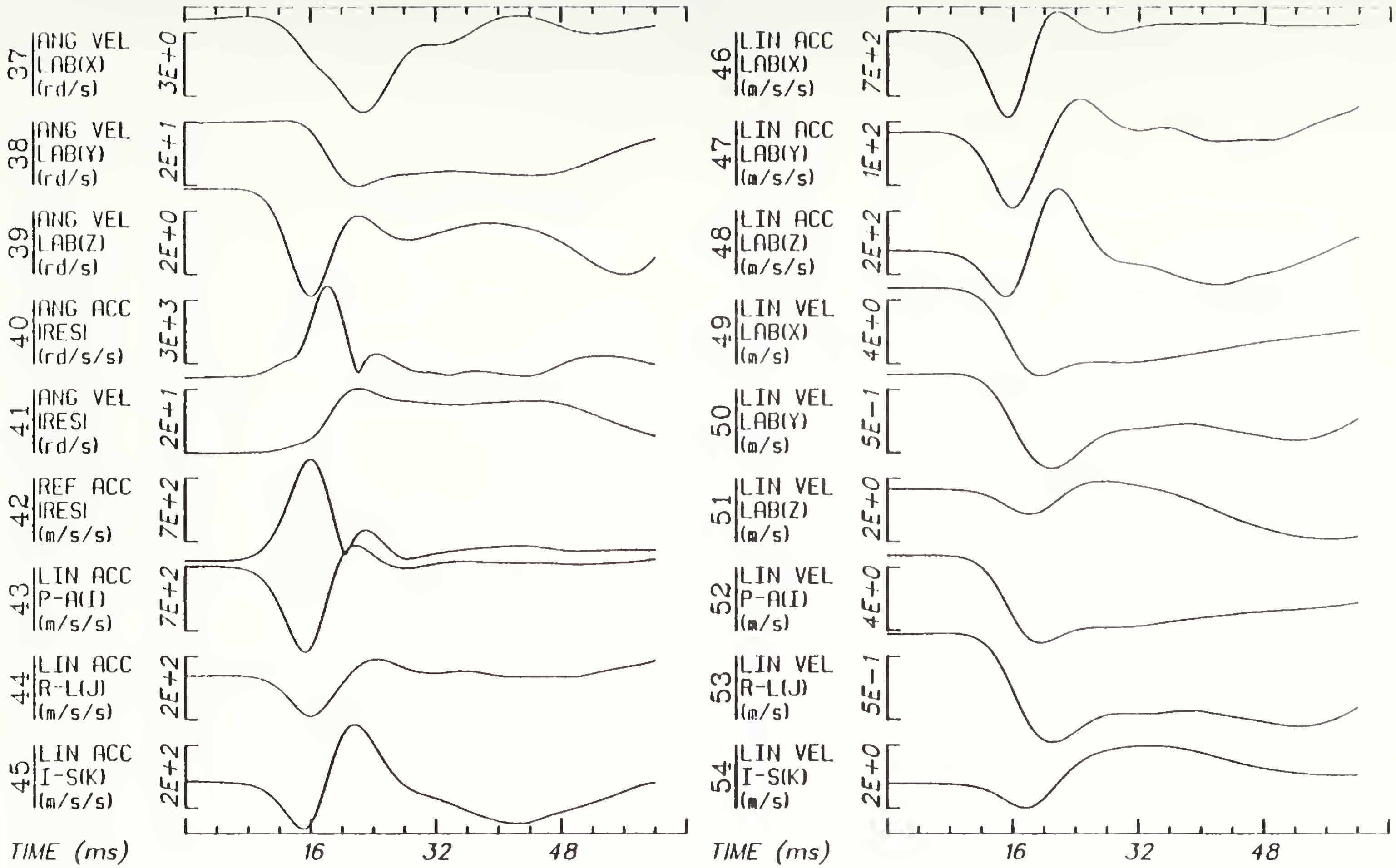

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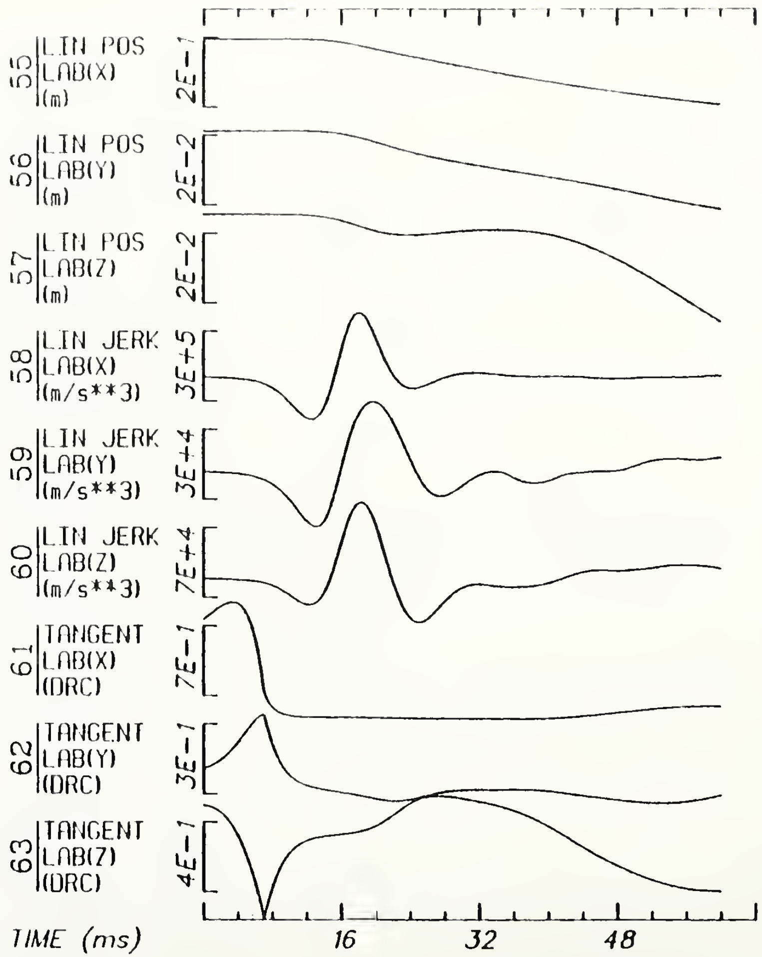
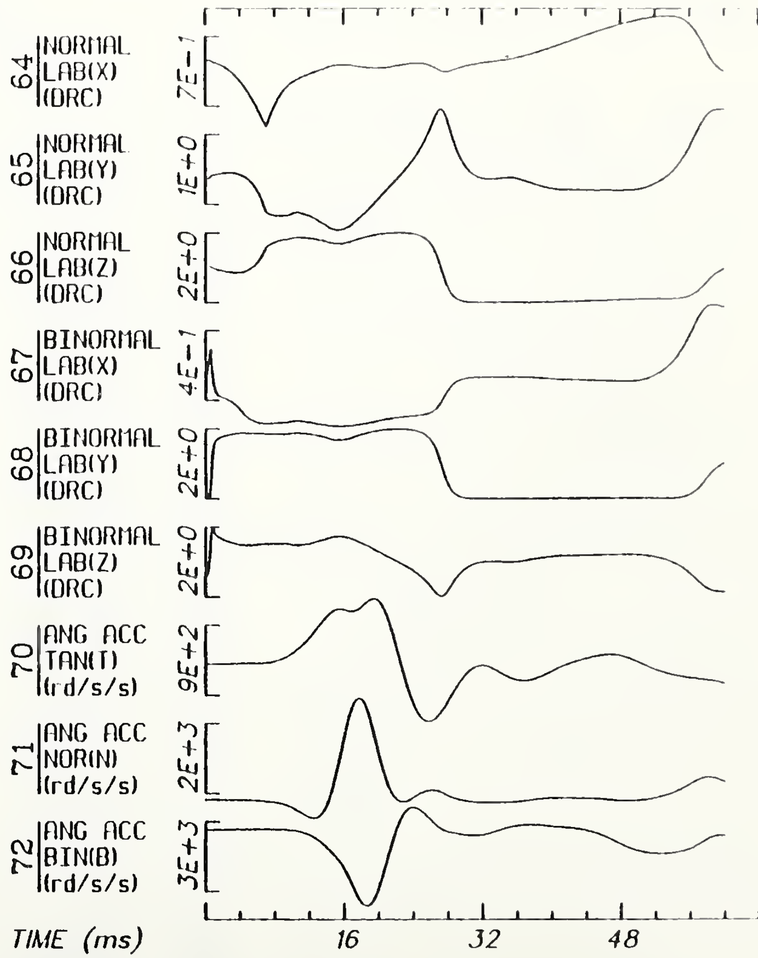
*Filter: 100*4C*

C43





Run ID: 82E041 Disk: E041.3D. File: 1 Date: MAR 7, 1985 Sheet: 4

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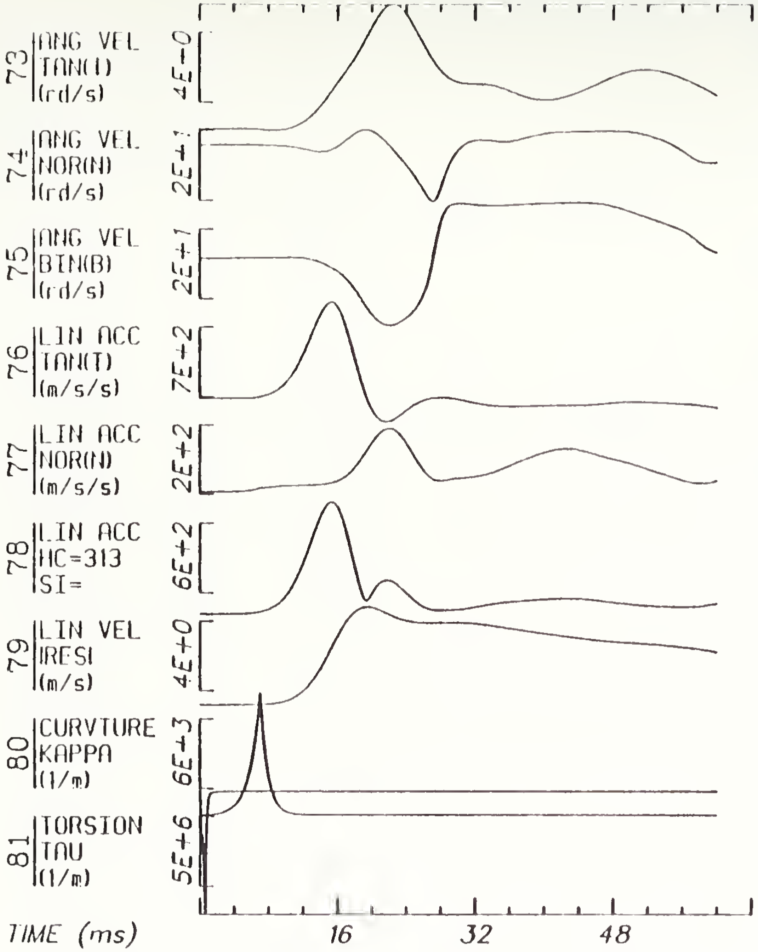

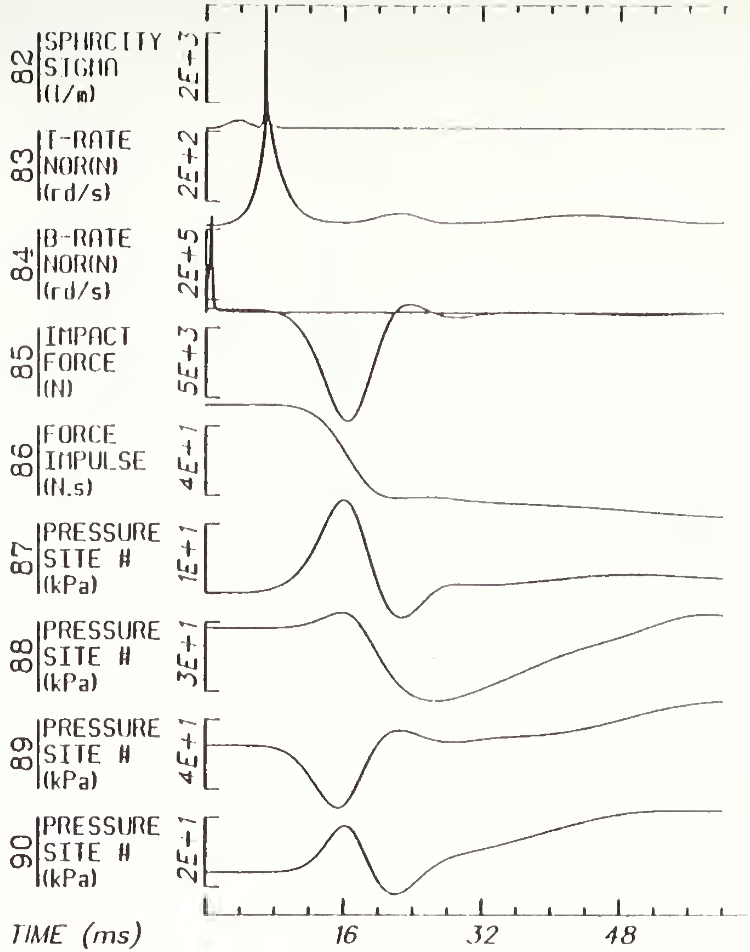

Run ID: 82E041 Disk: E041.3D. File: 1 Date: MAR 7, 1985 Sheet: 5

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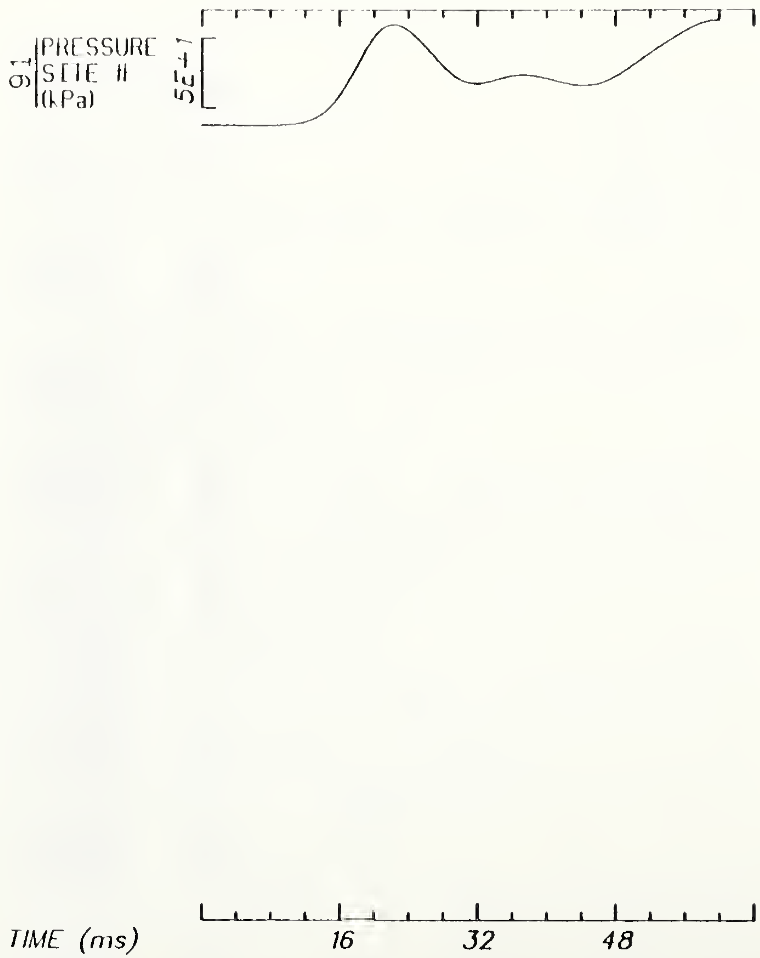
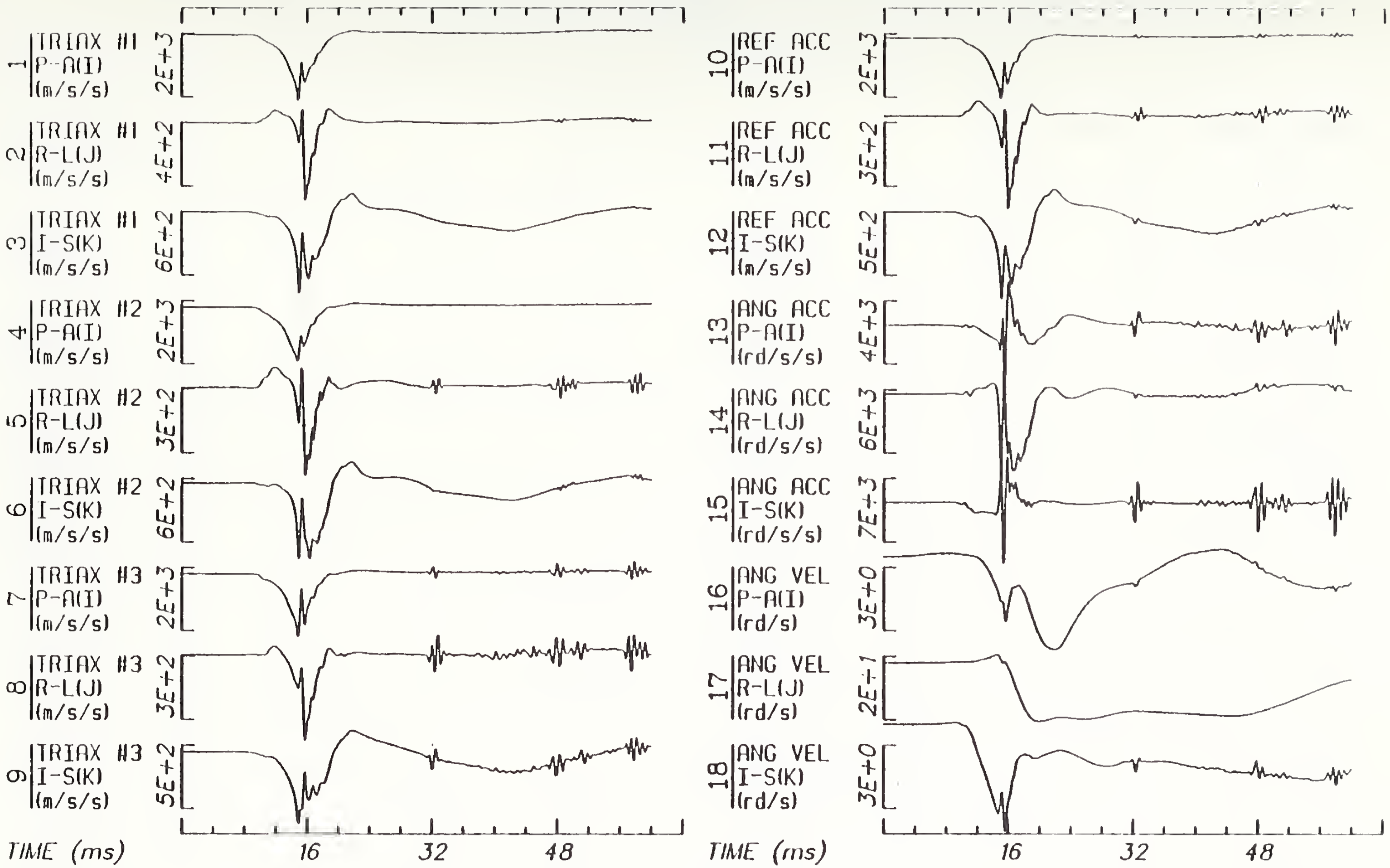


Run ID: 82E041 Disk: E041.3D. File: 1 Date: MAR 7, 1985 Sheet: 6

*Filter: 100*4C*

C46



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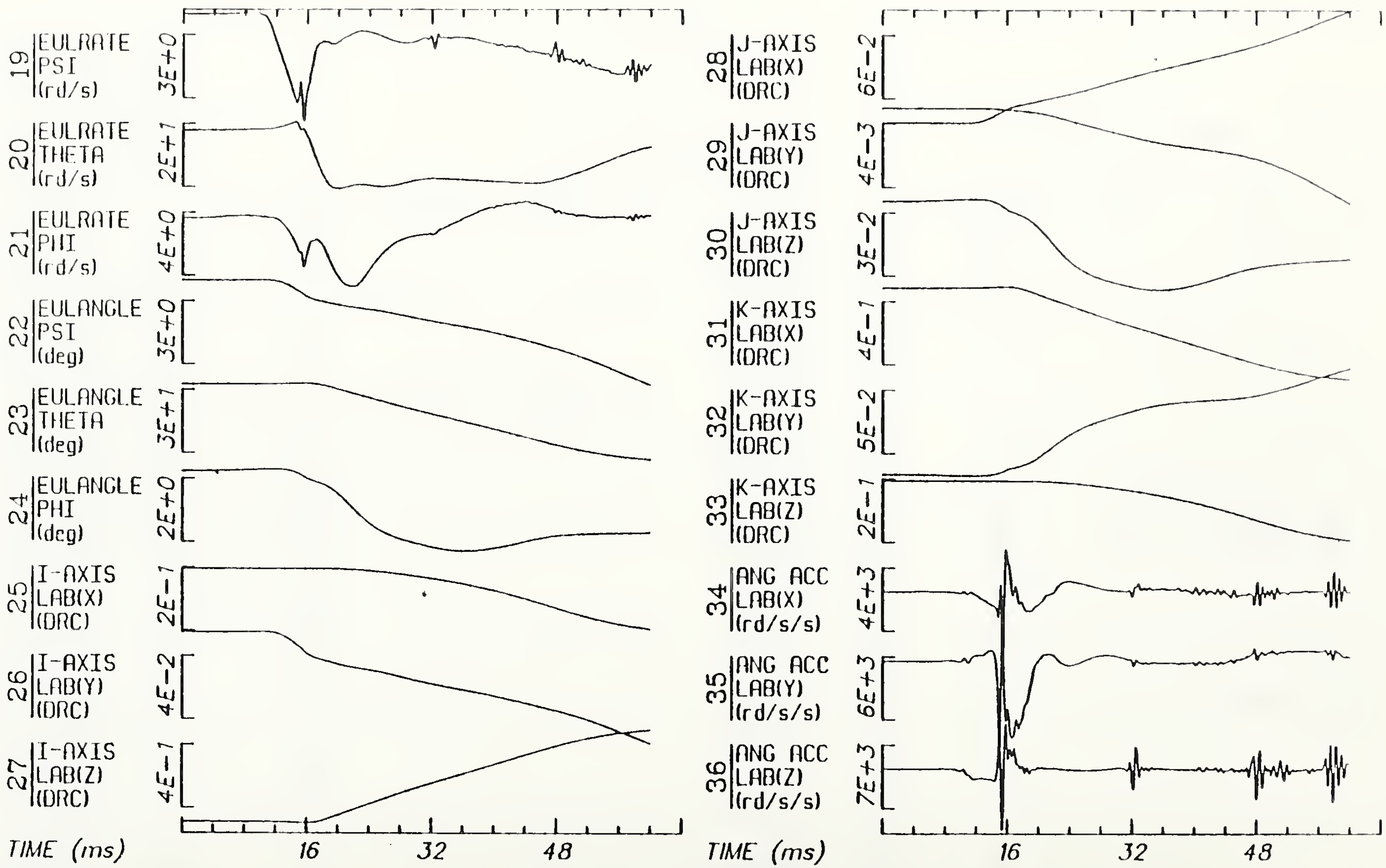
No Filtering

C47



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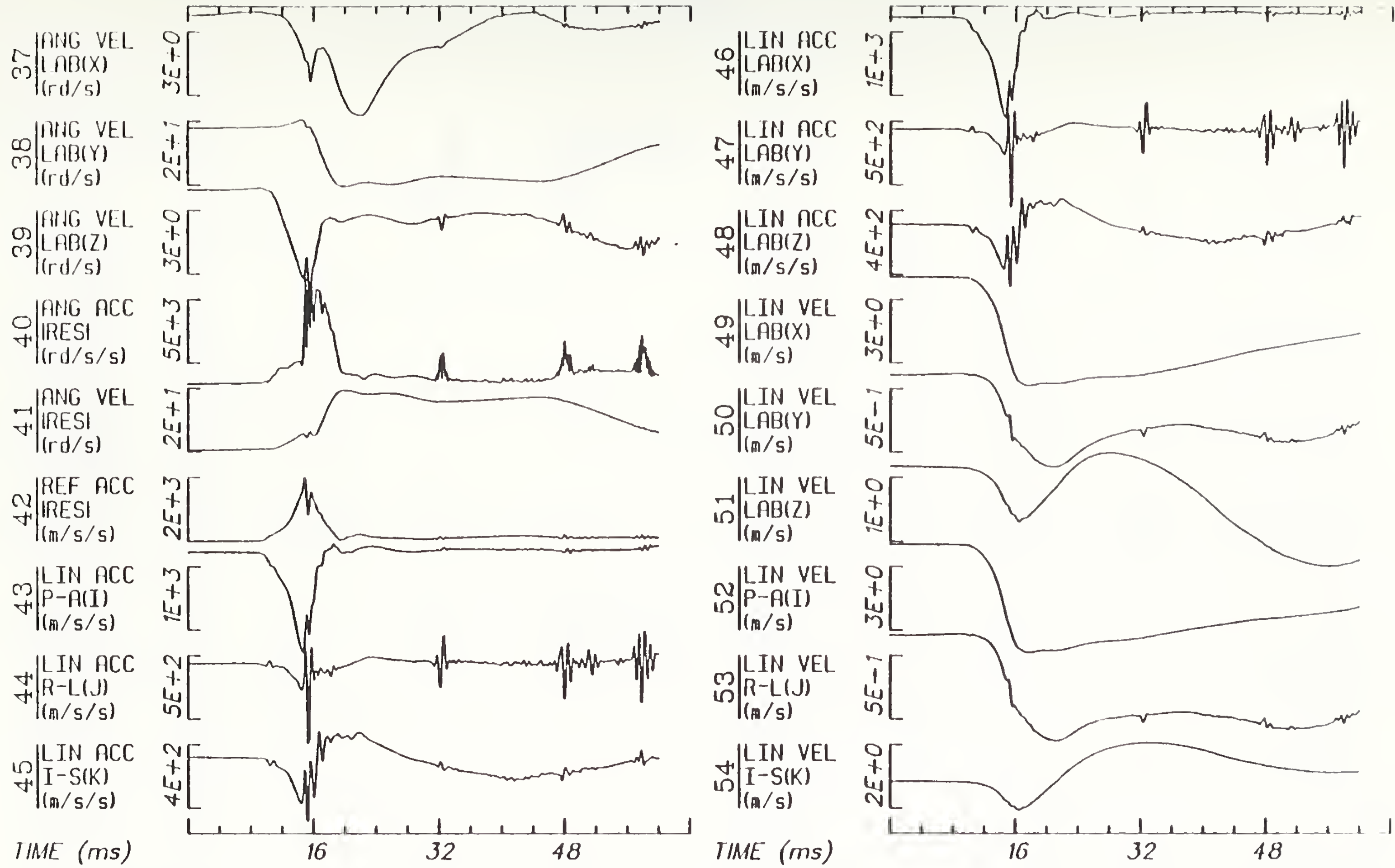
No Filtering

C48



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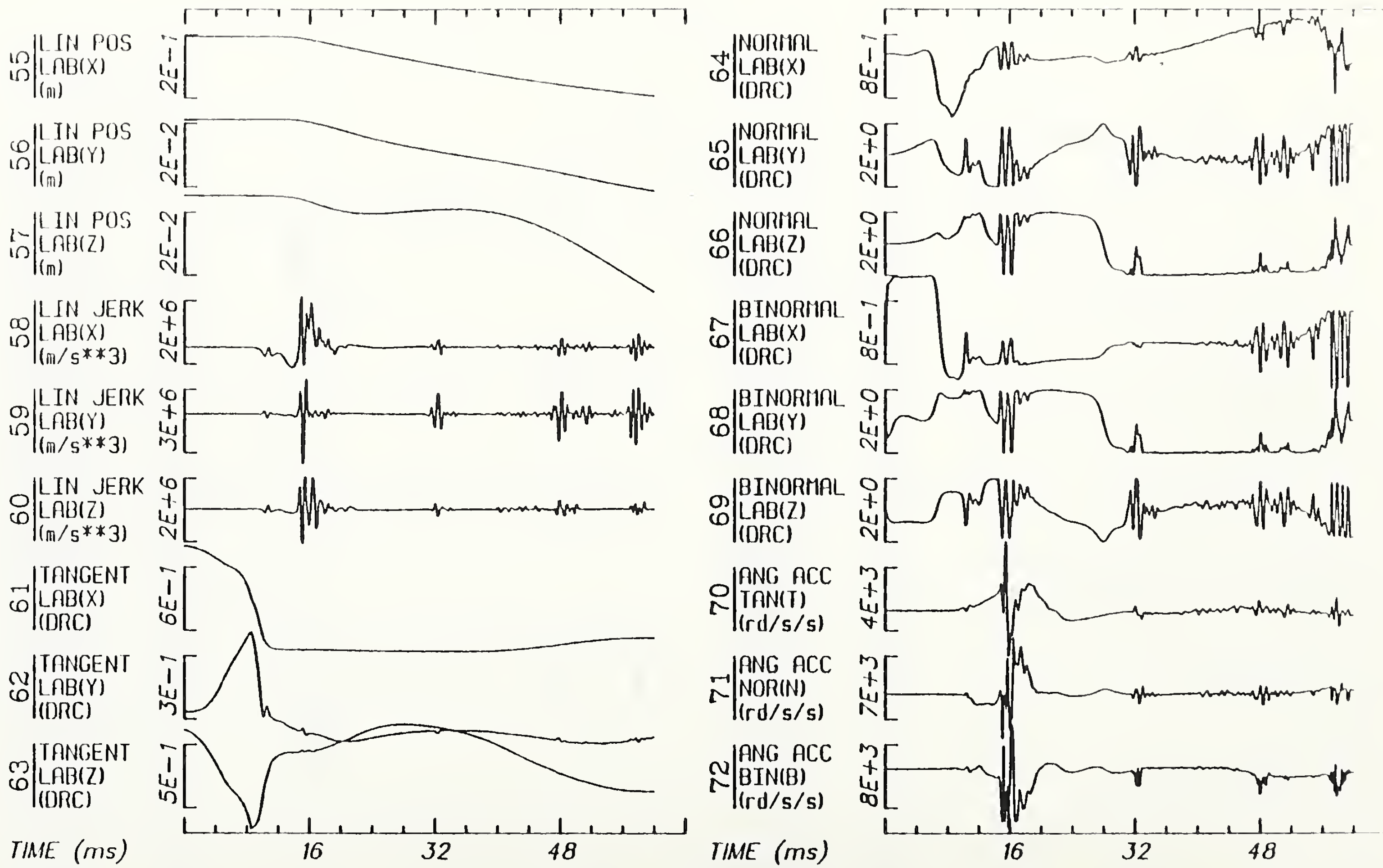
No Filtering



Run ID: 82E041 Disk: E041.3D. File: 1 Date: MAR 7, 1985 Sheet: 4

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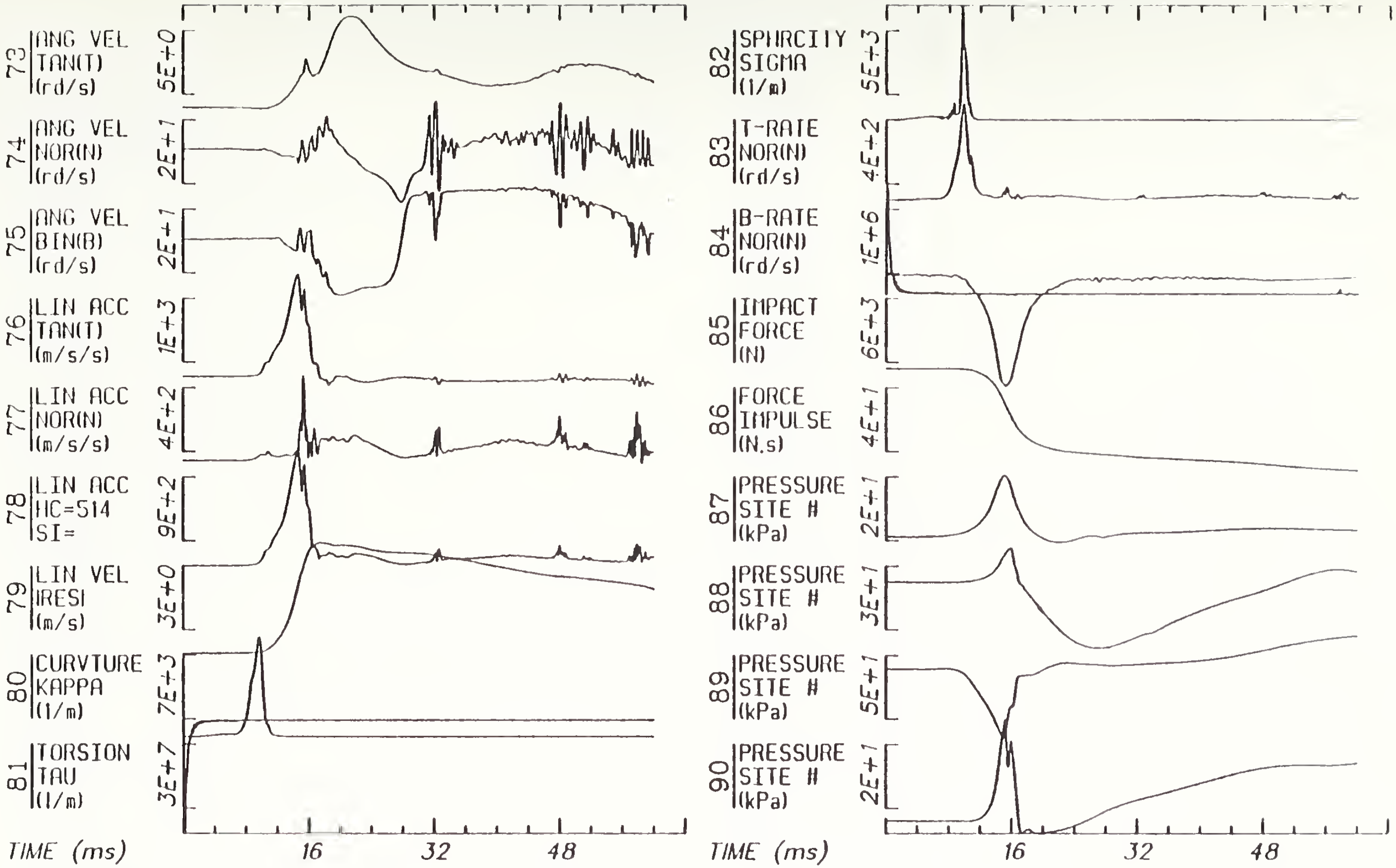

Run ID: 82E041 Disk: E041.3D. File: 1 Date: MAR 7, 1985 Sheet: 5

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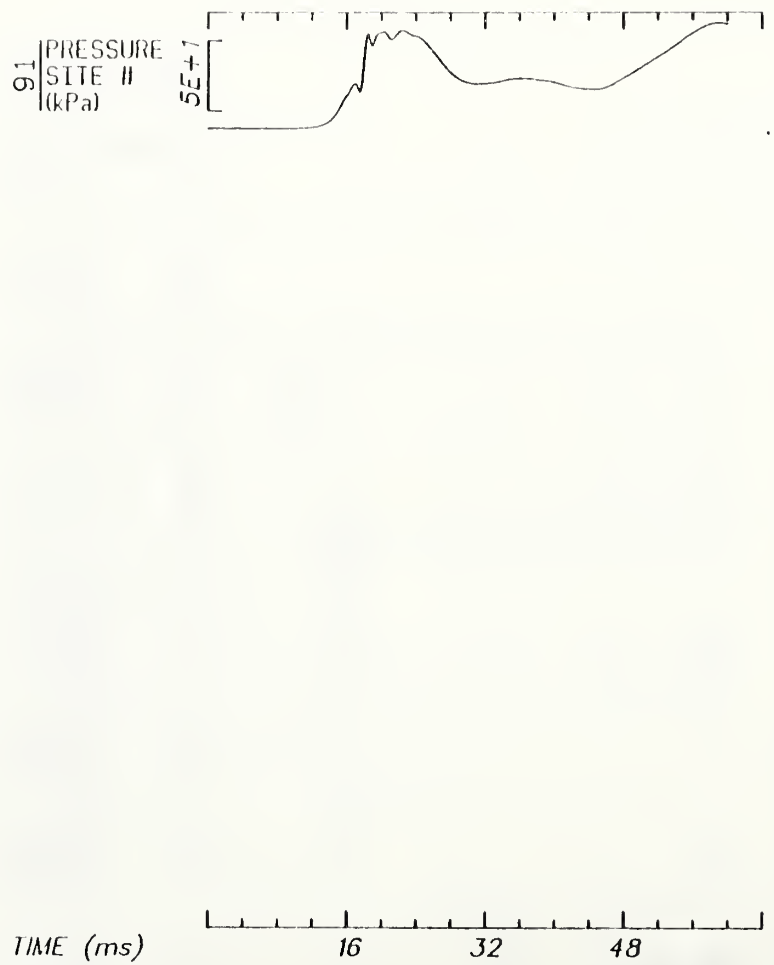

Run ID: 82E041 Disk: E041.3D. File: 1 Date: MAR 7, 1985 Sheet: 6

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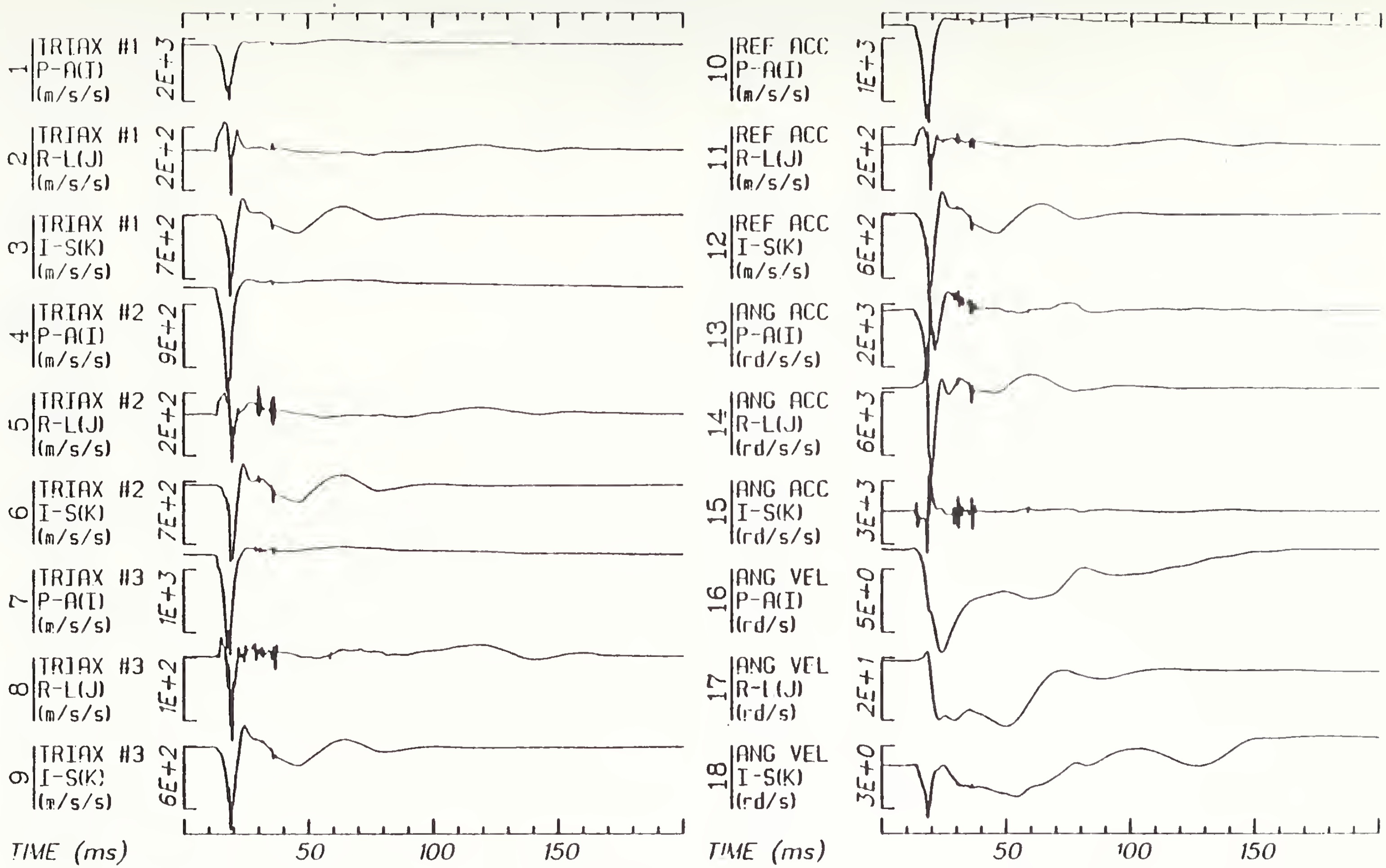
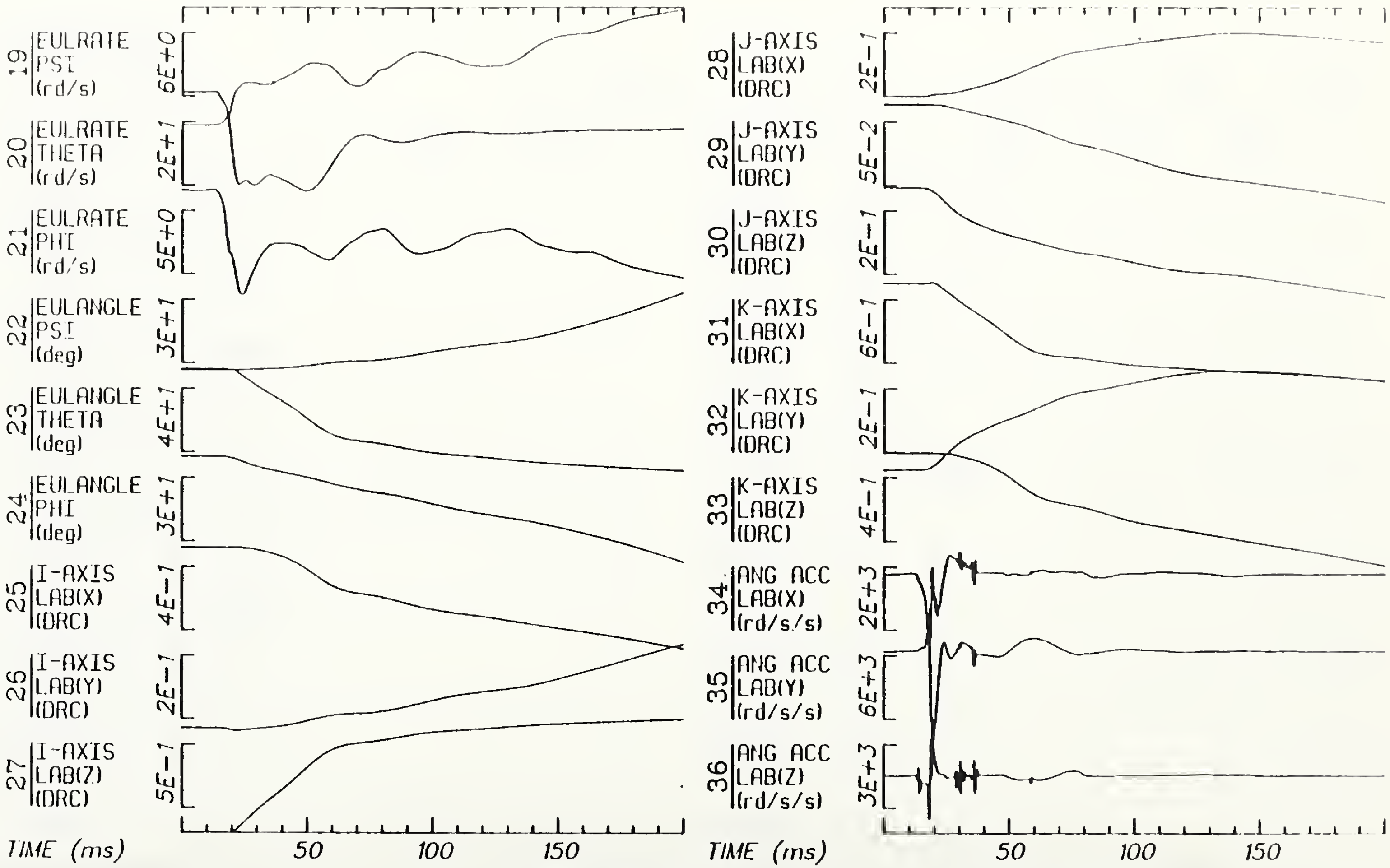


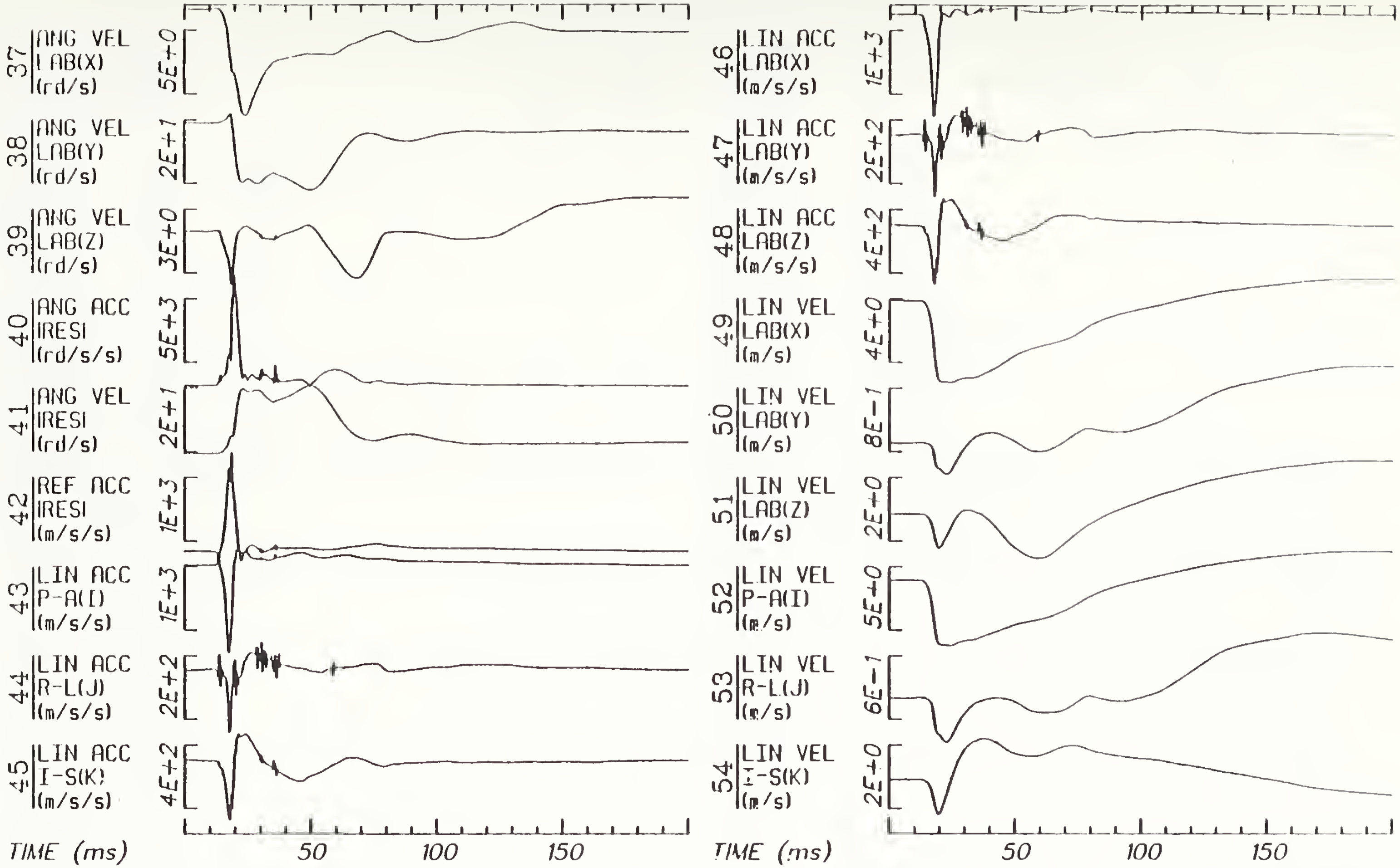
Run ID: 82E042 Disk: -HEAD File: 2 Date: MAR 11, 1985 Sheet: 1

*Filter:1600*4C*



Run ID: 82E042 Disk: –HEAD File: 2 Date: MAR 11, 1985 Sheet: 2

*Filter:1600*4C*



Run ID: 82E042 Disk: -HEAD File: 2 Date: MAR 11, 1985 Sheet: 3

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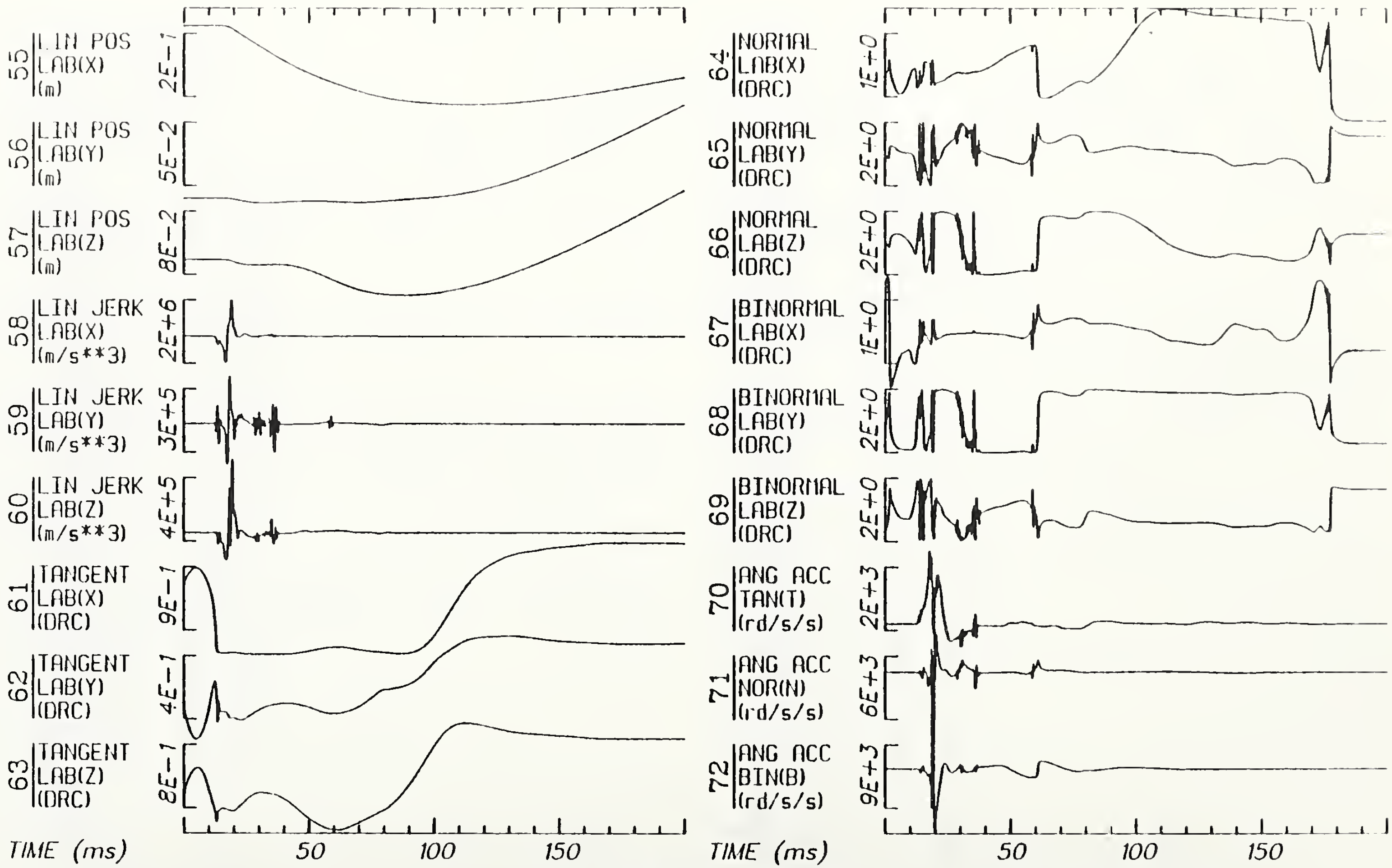

Run ID: 82E042 Disk: -HEAD File: 2 Date: MAR 11, 1985 Sheet: 4

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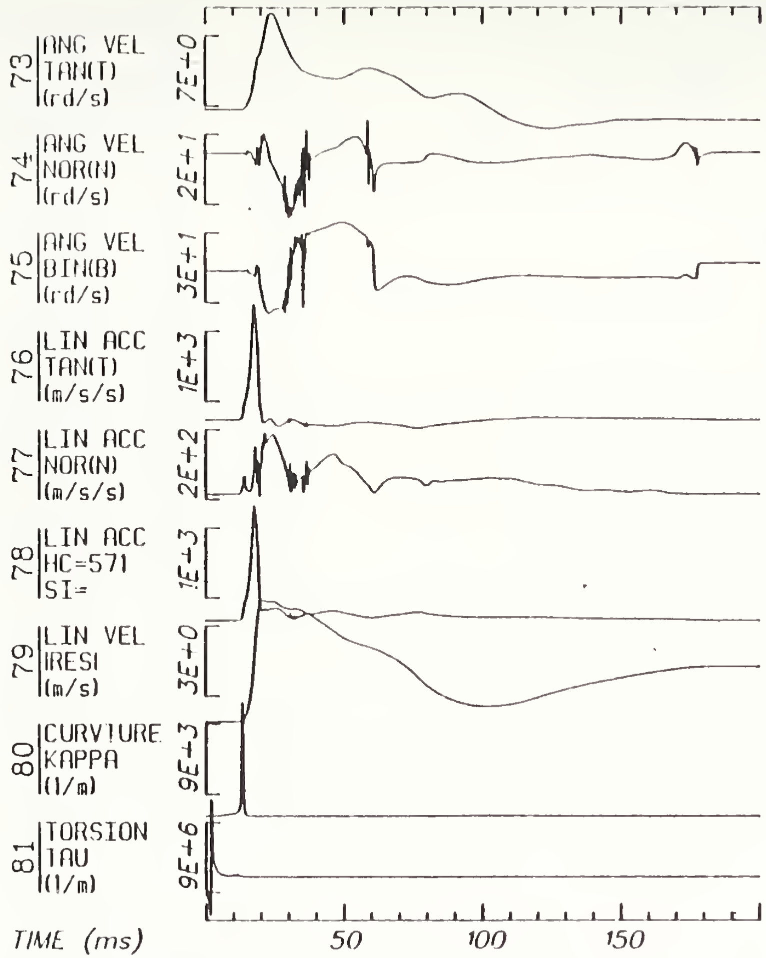

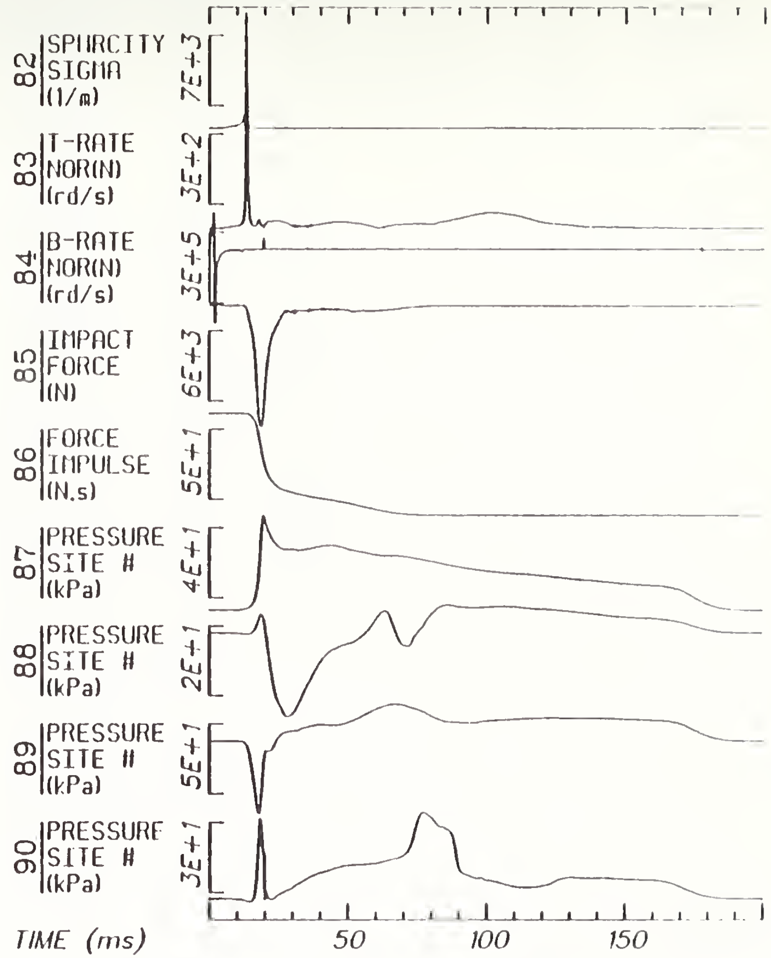

Run ID: 82E042 Disk: -HEAD File: 2 Date: MAR 11, 1985 Sheet: 5

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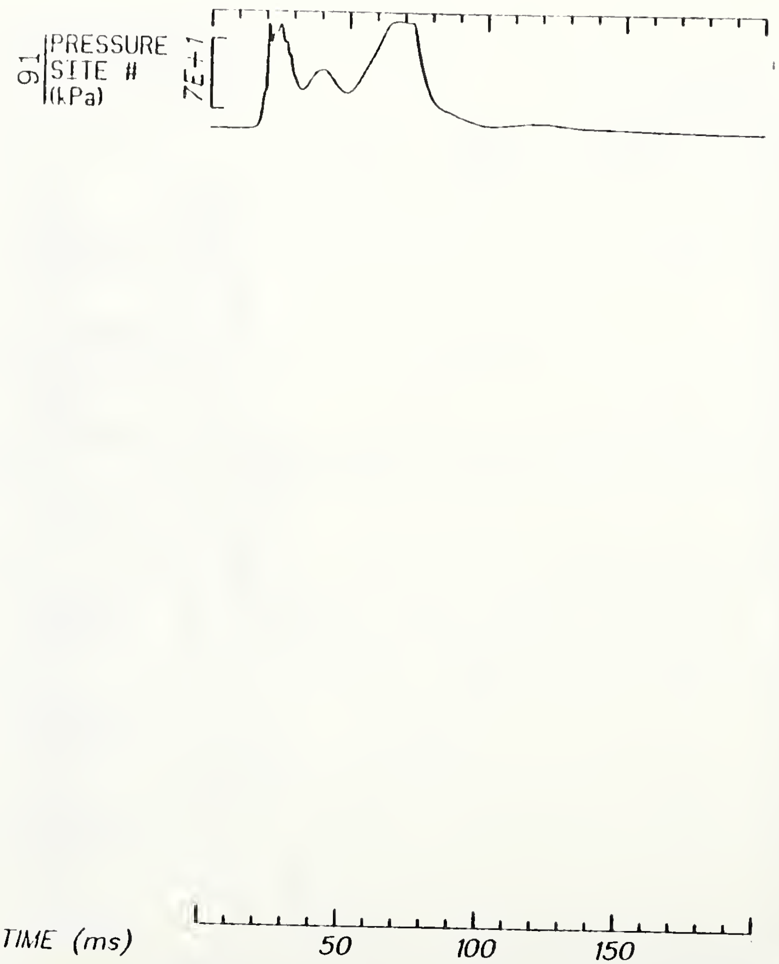
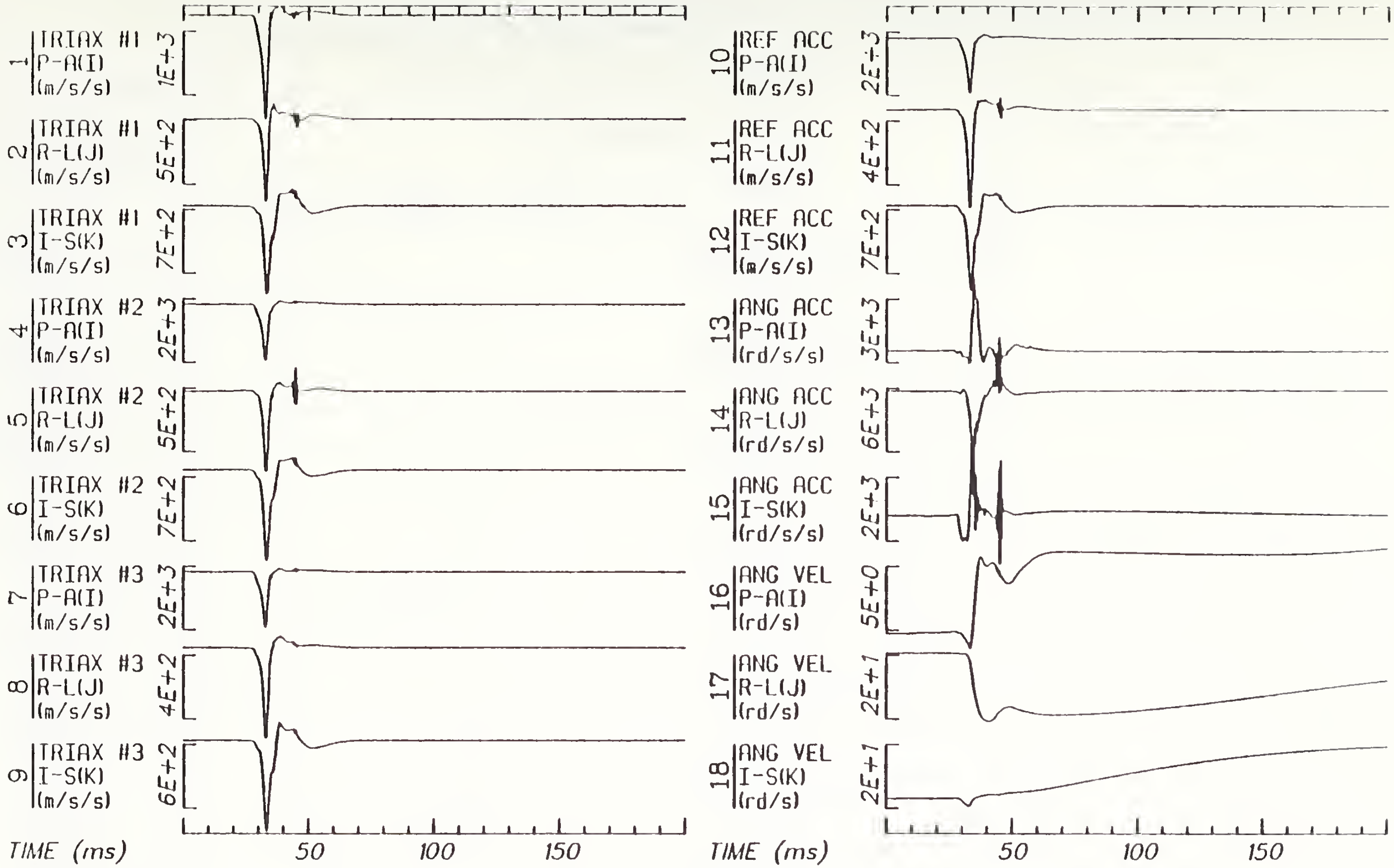


TIME (ms)

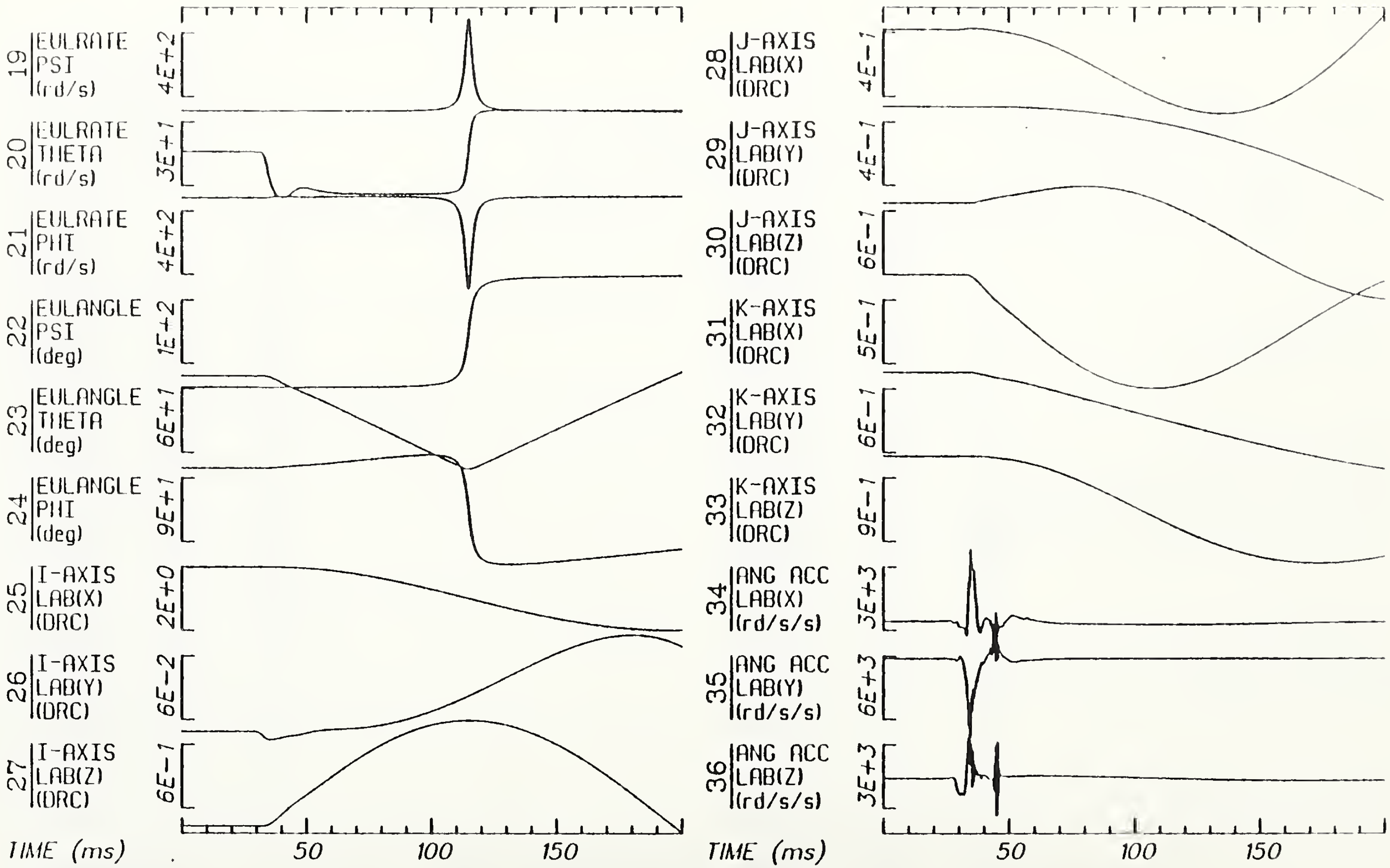
Run ID: 82E042 Disk: −HEAD File: 2 Date: MAR 11, 1985 Sheet: 6

*Filter:1600*4C*



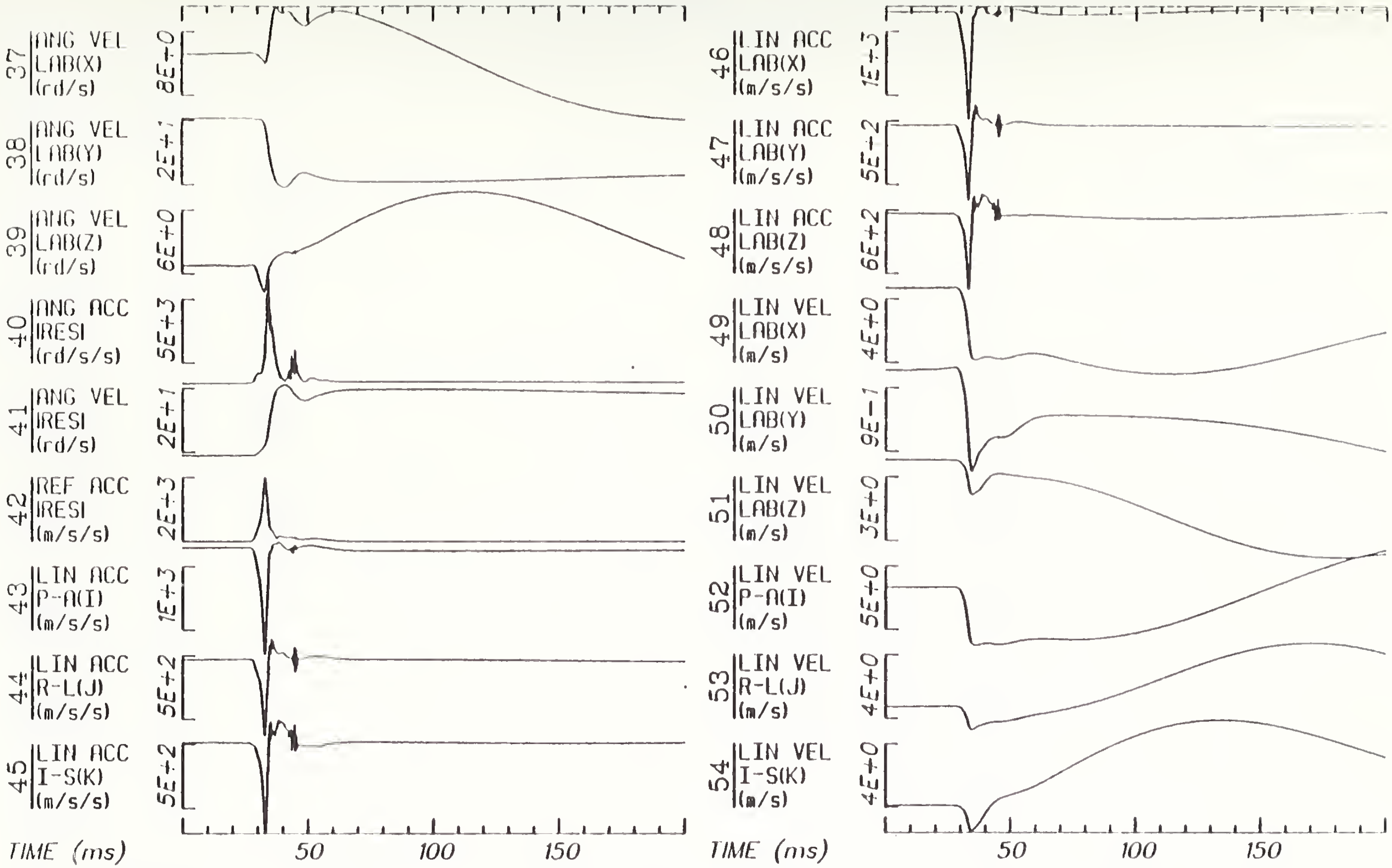
Run ID: 82E061 Disk: 82E061.3 File: 1 Date: MAR 21, 1985 Sheet: 1

*Filter:1600*4C*



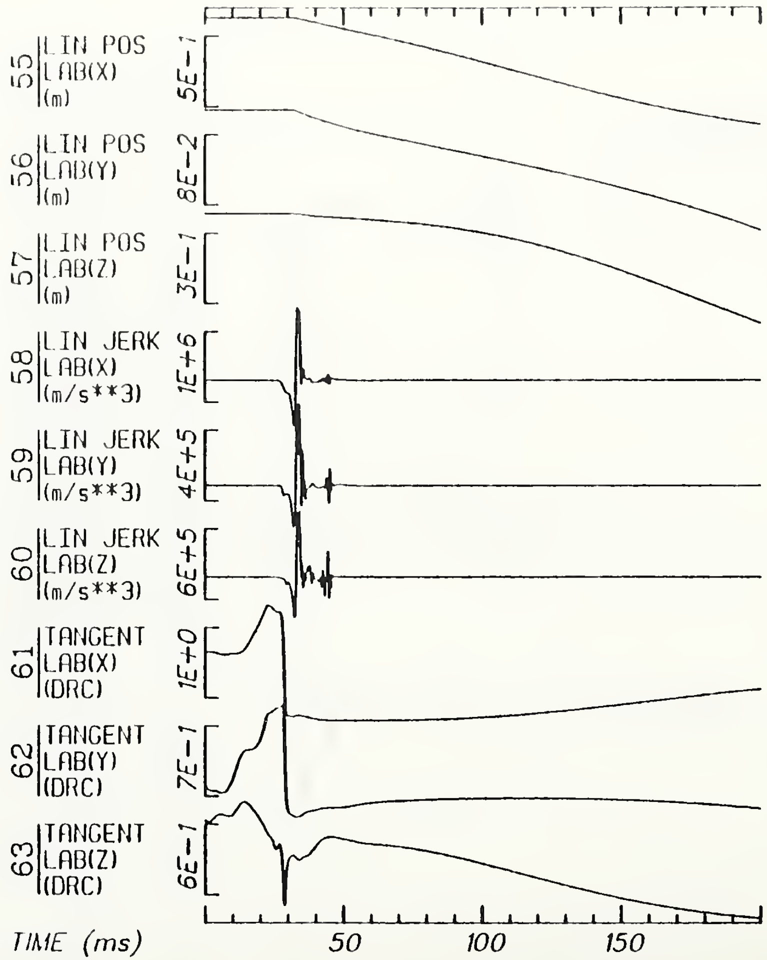
Run ID: 82E061 Disk: 82E061.3 File: 1 Date: MAR 21, 1985 Sheet: 2

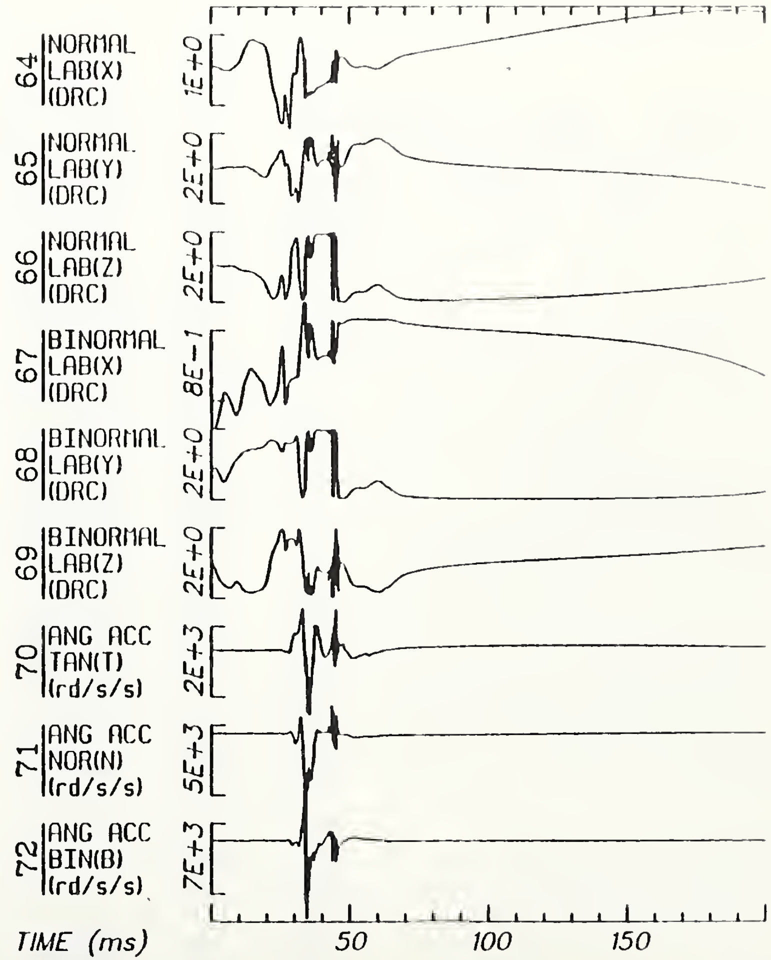
*Filter:1600*4C*



Run ID: 82E061 Disk: 82E061.3 File: 1 Date: MAR 21, 1985 Sheet: 3

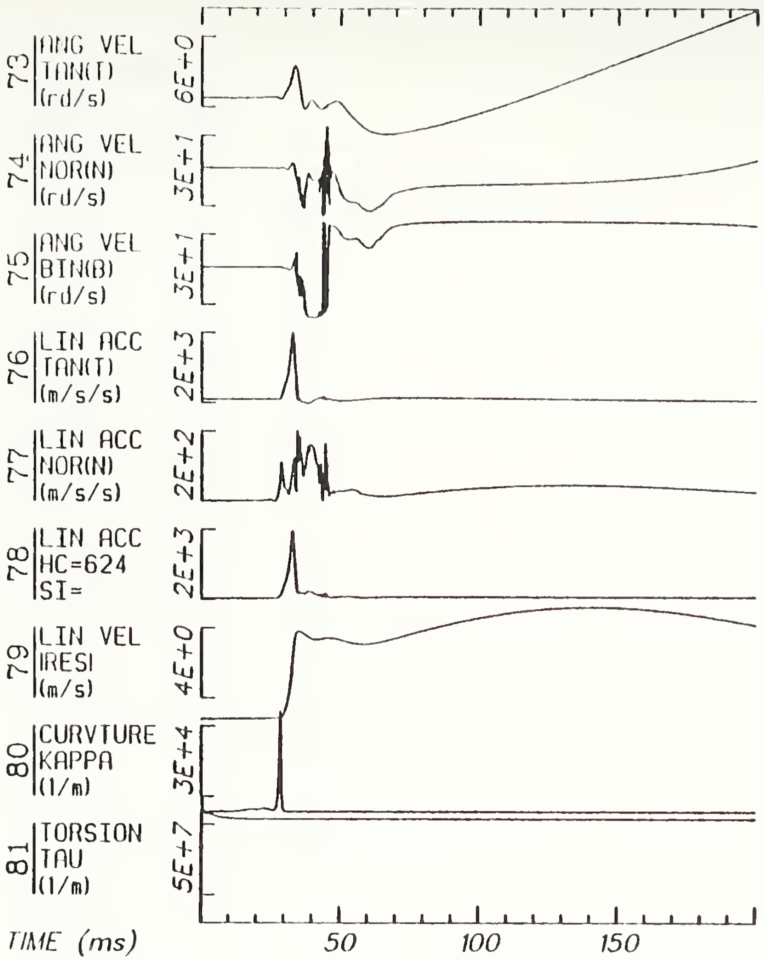
Filter:1600*4C

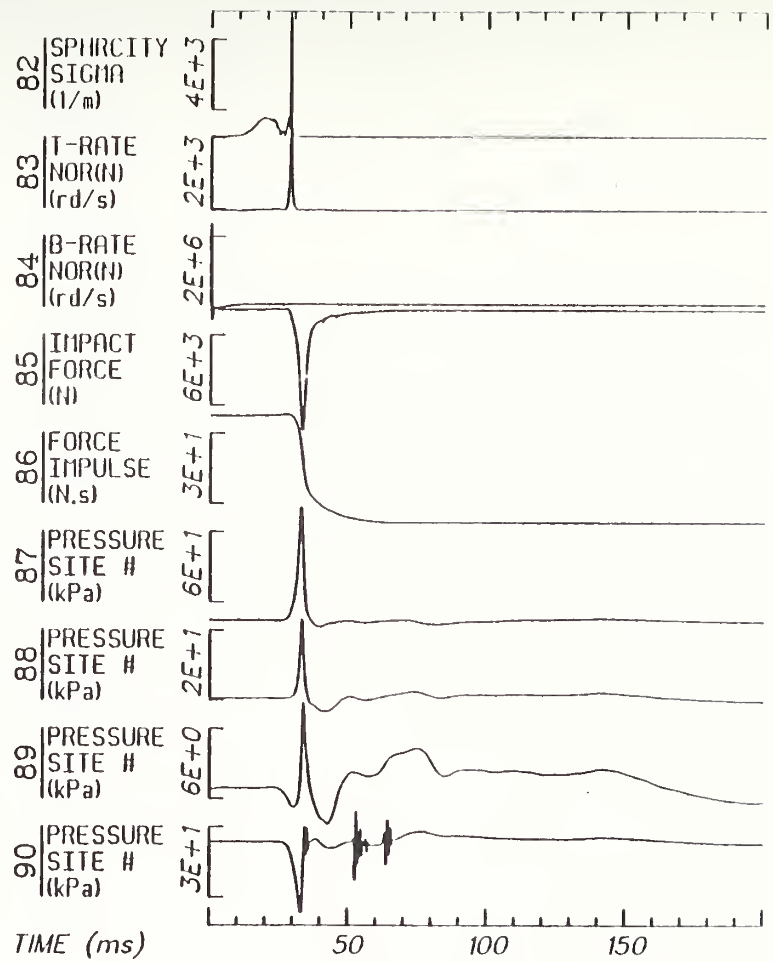




Run ID: 82E061 Disk: 82E061.3 File: 1 Date: MAR 21, 1985 Sheet: 4

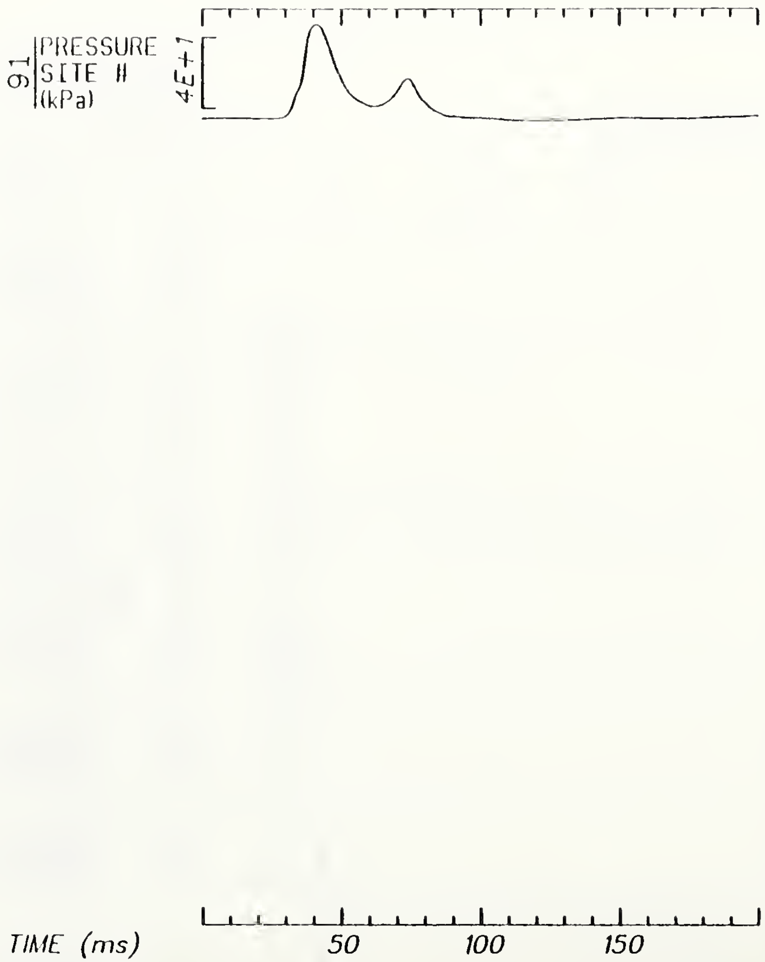
*Filter:1600*4C*





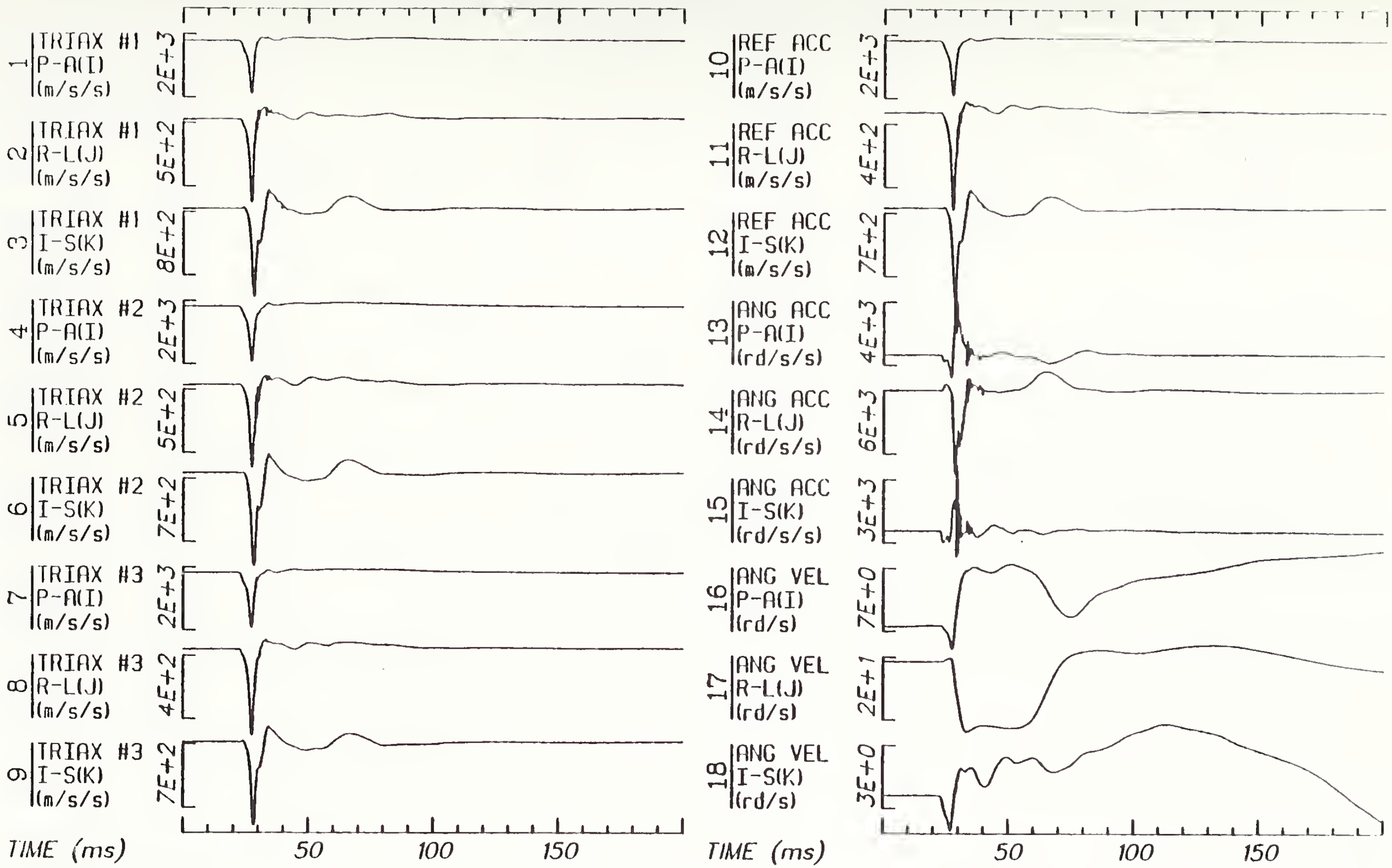
Run ID: 82E061 Disk: 82E061.3 File: 1 Date: MAR 21, 1985 Sheet: 5

*Filter:1600*4C*



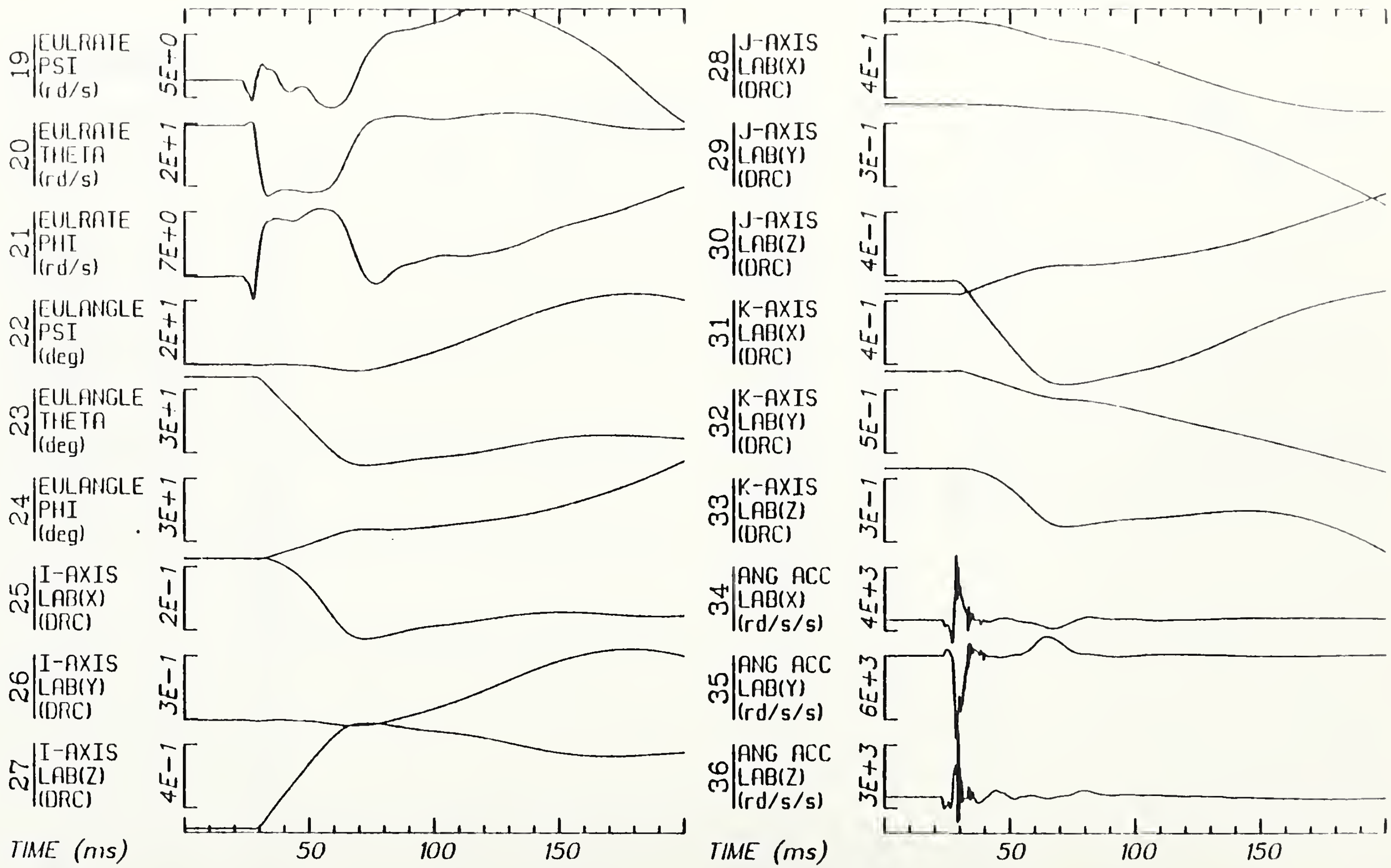
Run ID: 82E061 Disk: 82E061.3 File: 1 Date: MAR 21, 1985 Sheet: 6

*Filter:1600*4C*



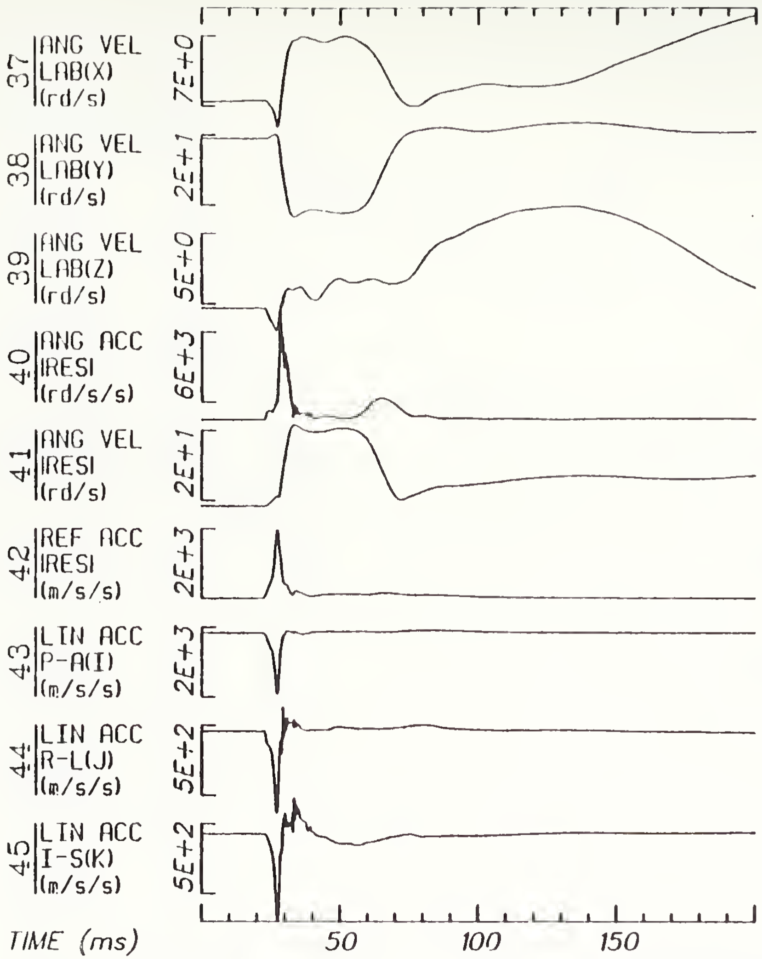
Run ID: 82E062 Disk: 82E062.3 File: 1 Date: APR 1, 1985 Sheet: 1

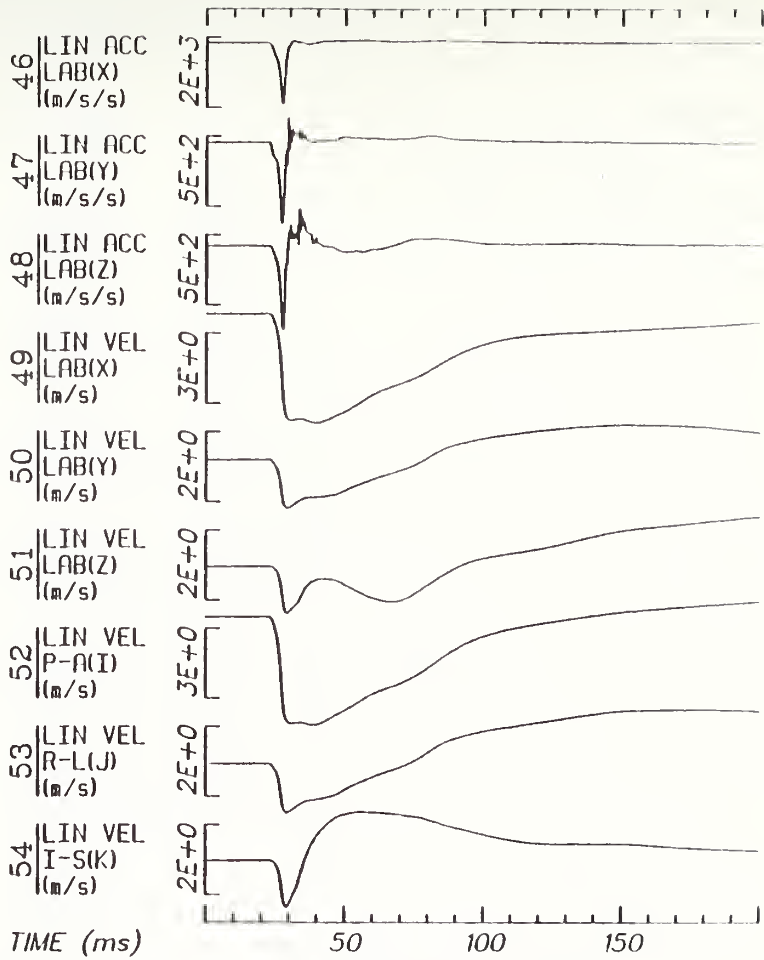
*Filter:1600*4C*



Run ID: 82E062 Disk: 82E062.3 File: 1 Date: APR 1, 1985 Sheet: 2

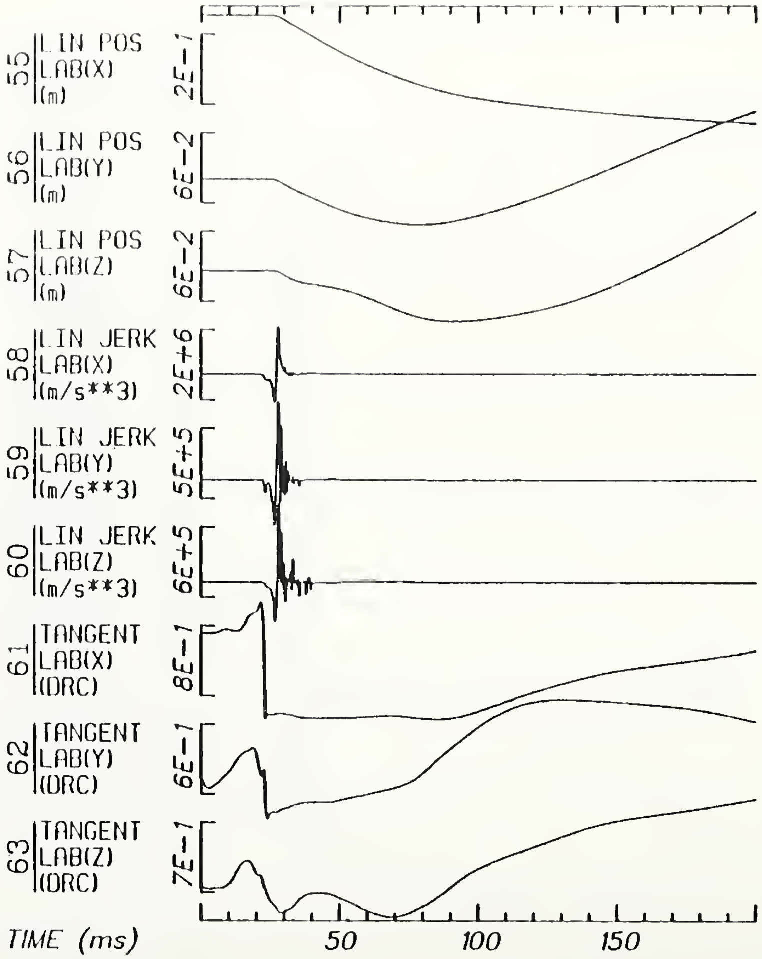
*Filter:1600*4C*

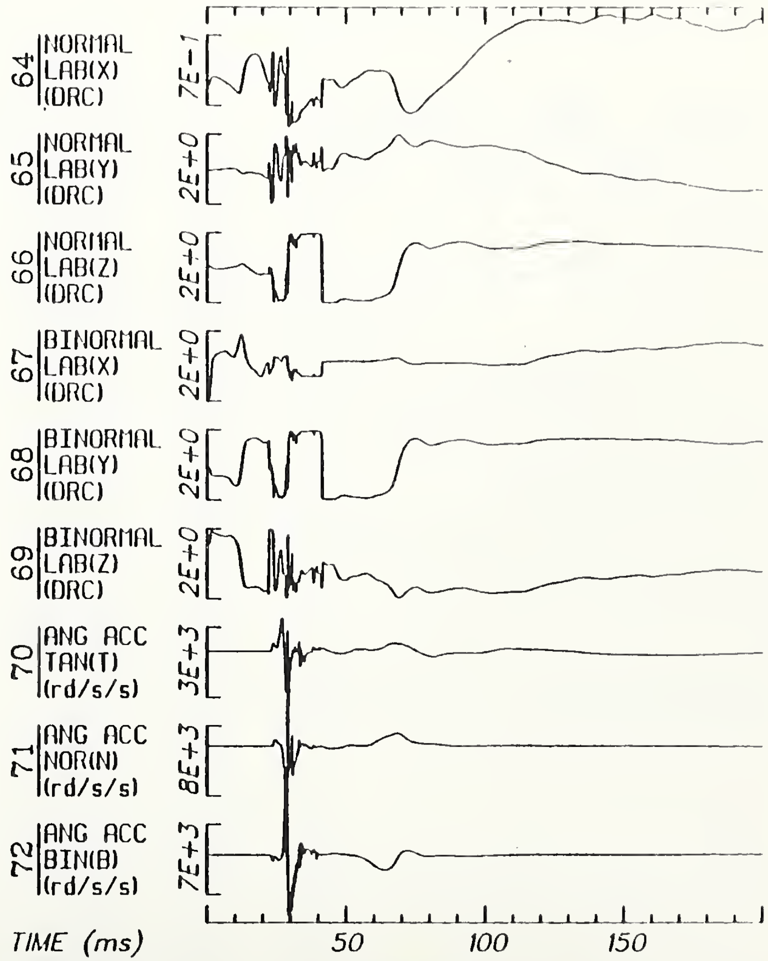




Run ID: 82E062 Disk: 82E062.3 File: 1 Date: APR 1, 1985 Sheet: 3

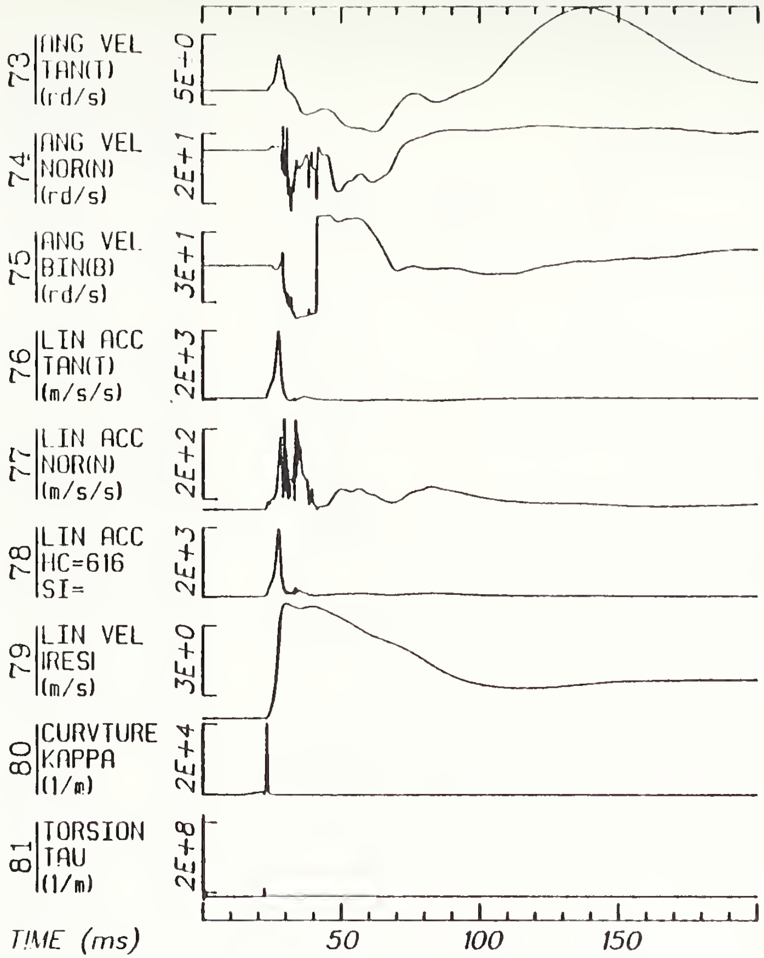
*Filter:1600*4C*

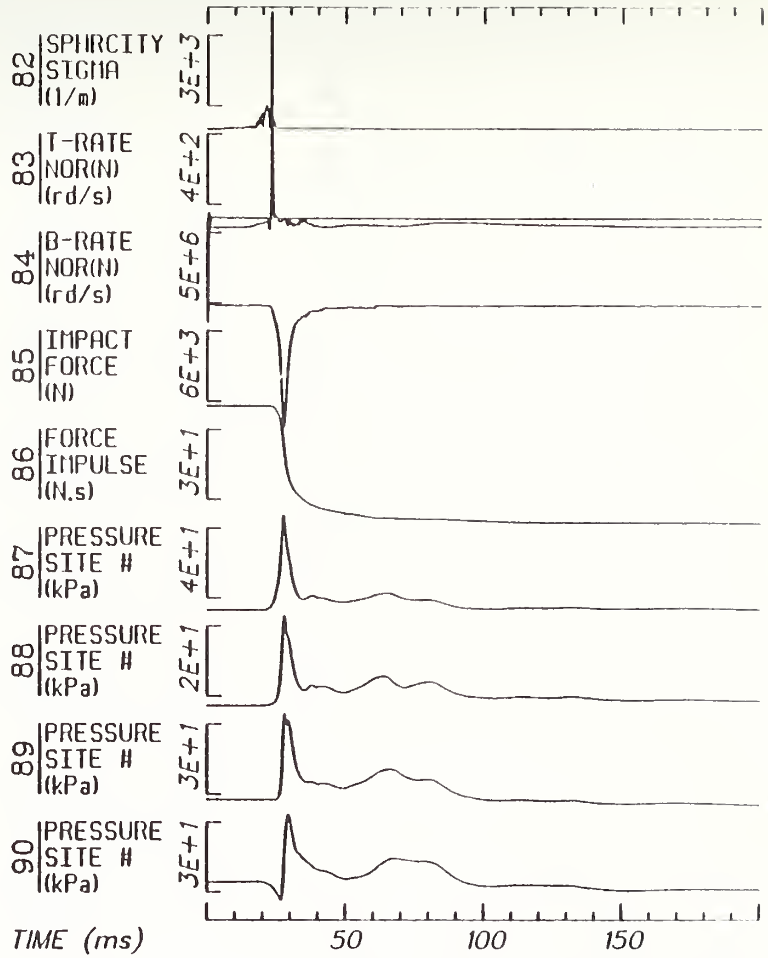




Run ID: 82E062 Disk: 82E062.3 File: 1 Date: APR 1, 1985 Sheet: 4

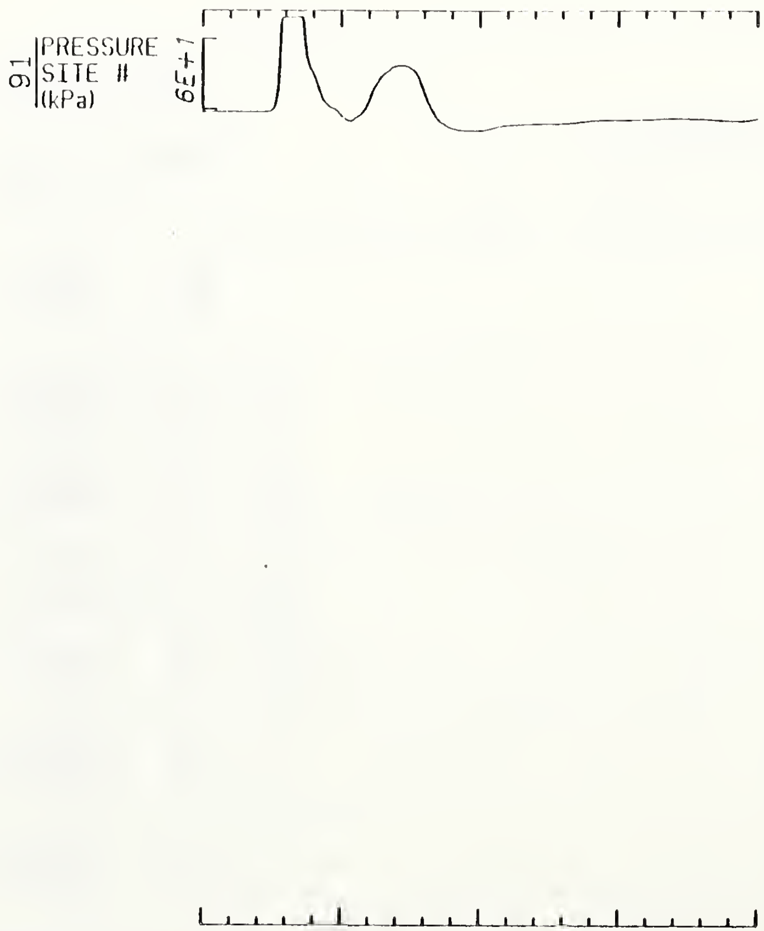
*Filter:1600*4C*





Run ID: 82E062 Disk: 82E062.3 File: 1 Date: APR 1, 1985 Sheet: 5

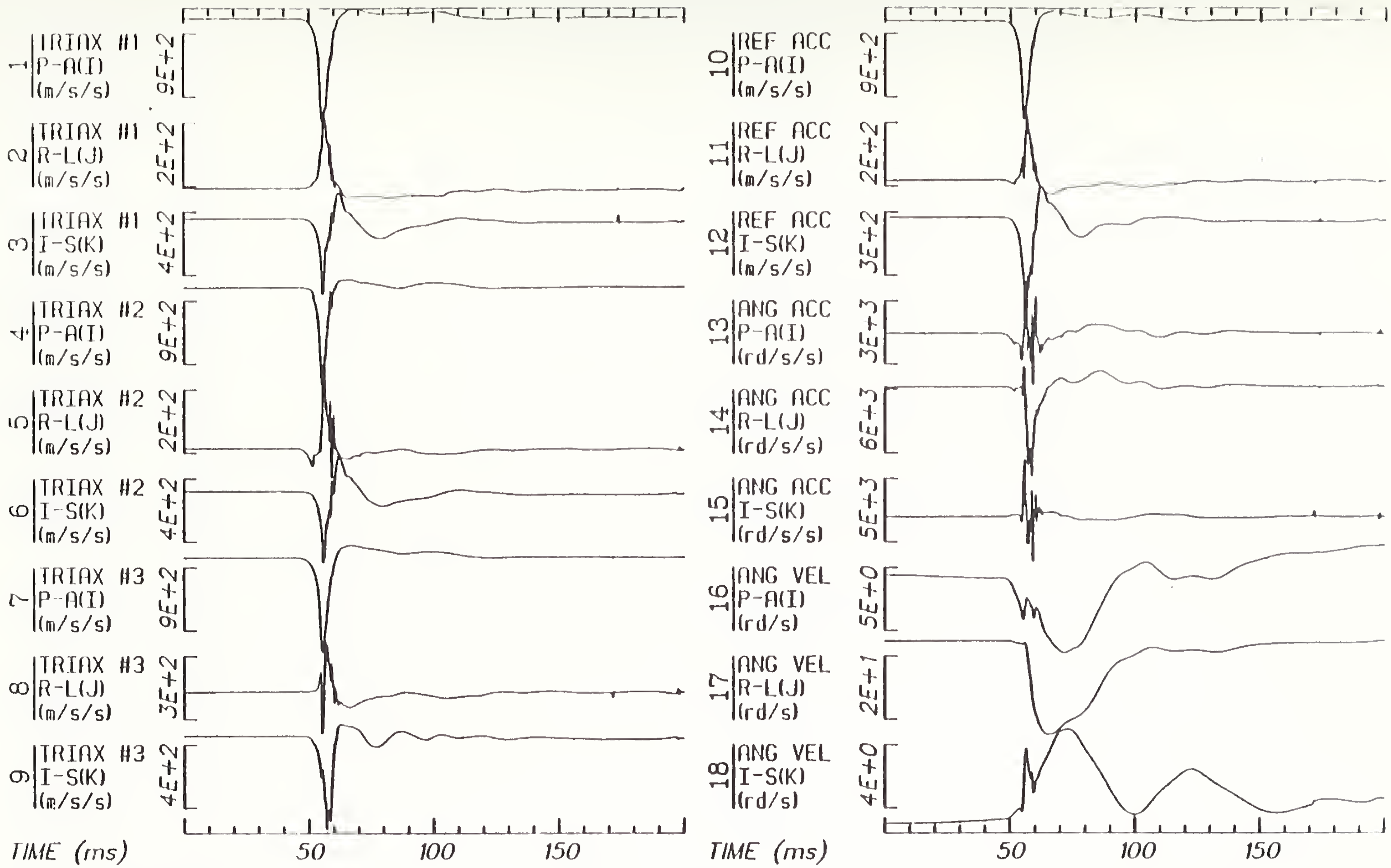
*Filter:1600*4C*



TIME (ms)

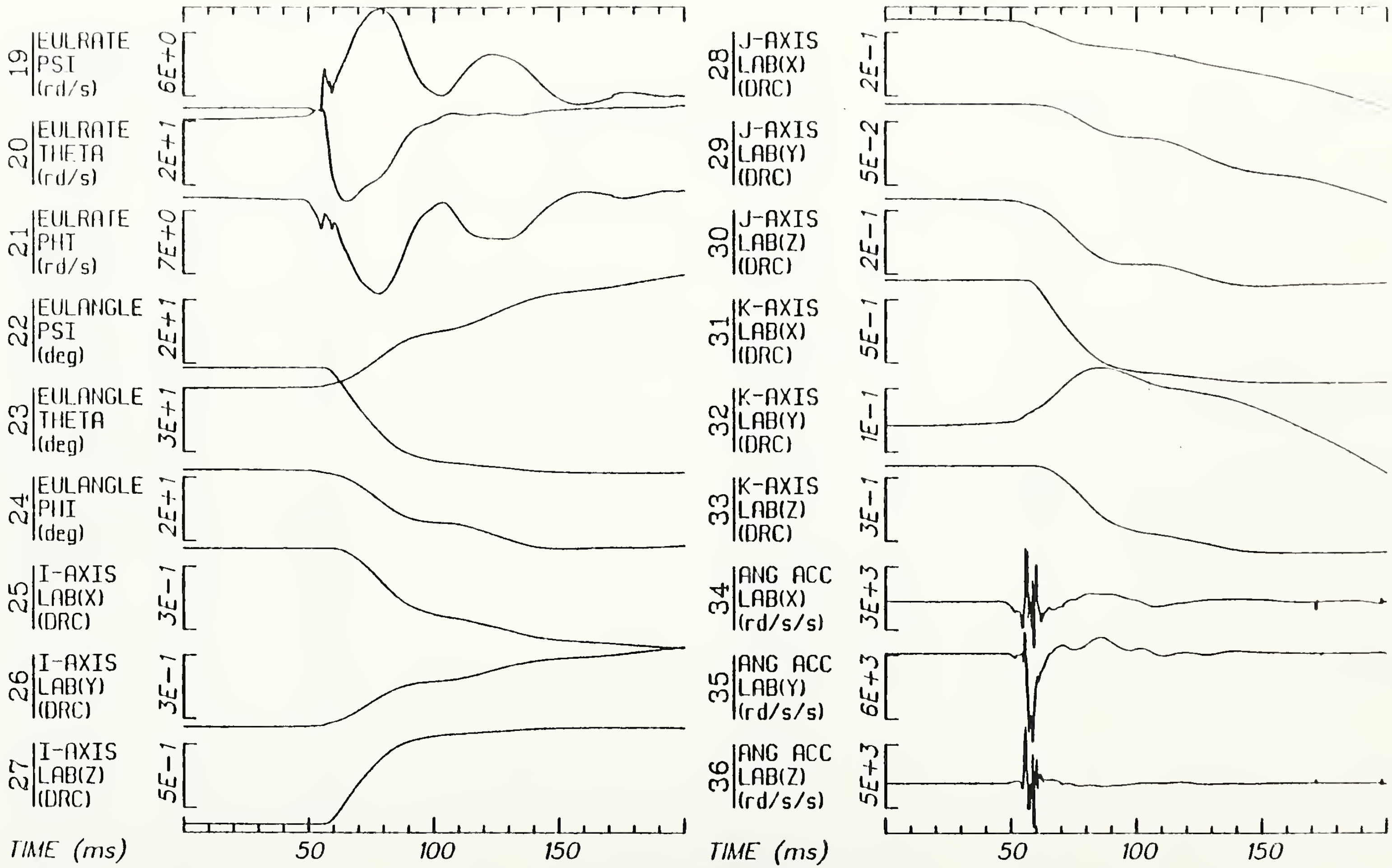
Run ID: 82E062 | Disk: 82E062.3 | File: 1 | Date: APR 1, 1985 | Sheet: 6

*Filter:1600*4C*



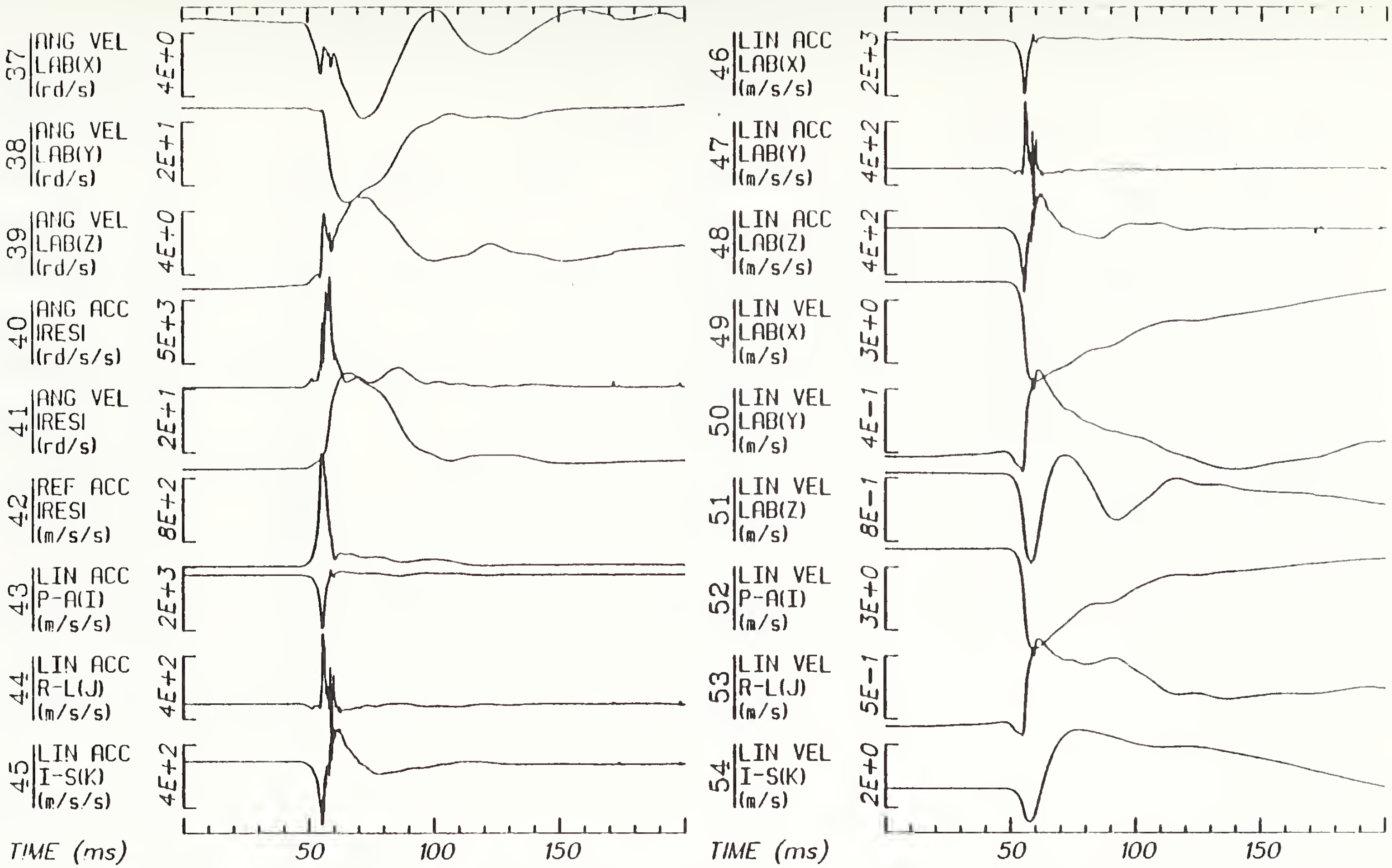
Run ID: 83E081 Disk: 83E081.3 File: 1 Date: APR 1, 1985 Sheet: 1

*Filter:1600*4C*



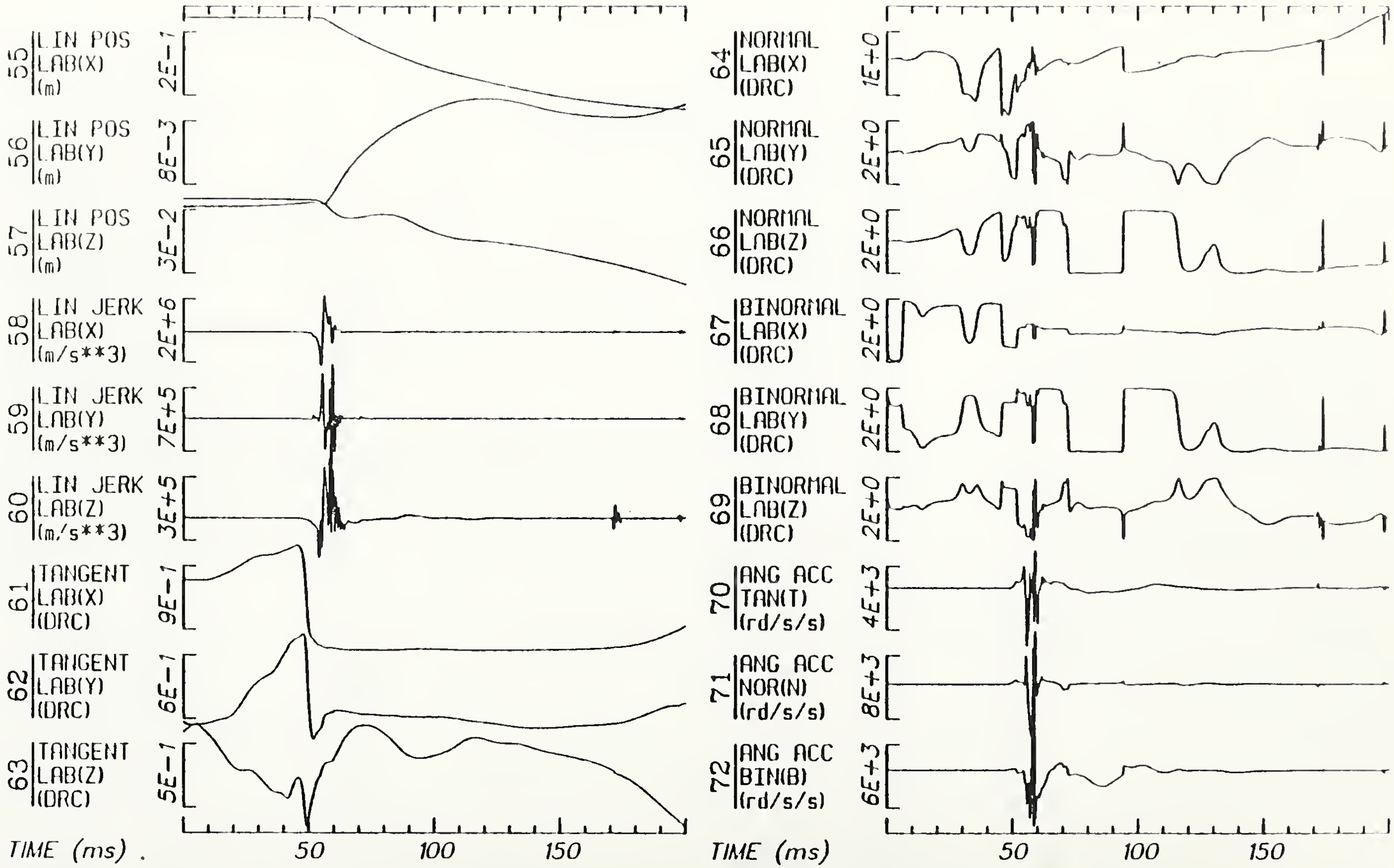
Run ID: 83E081 Disk: 83E081.3 File: 1 Date: APR 1, 1985 Sheet: 2

*Filter:1600*4C*



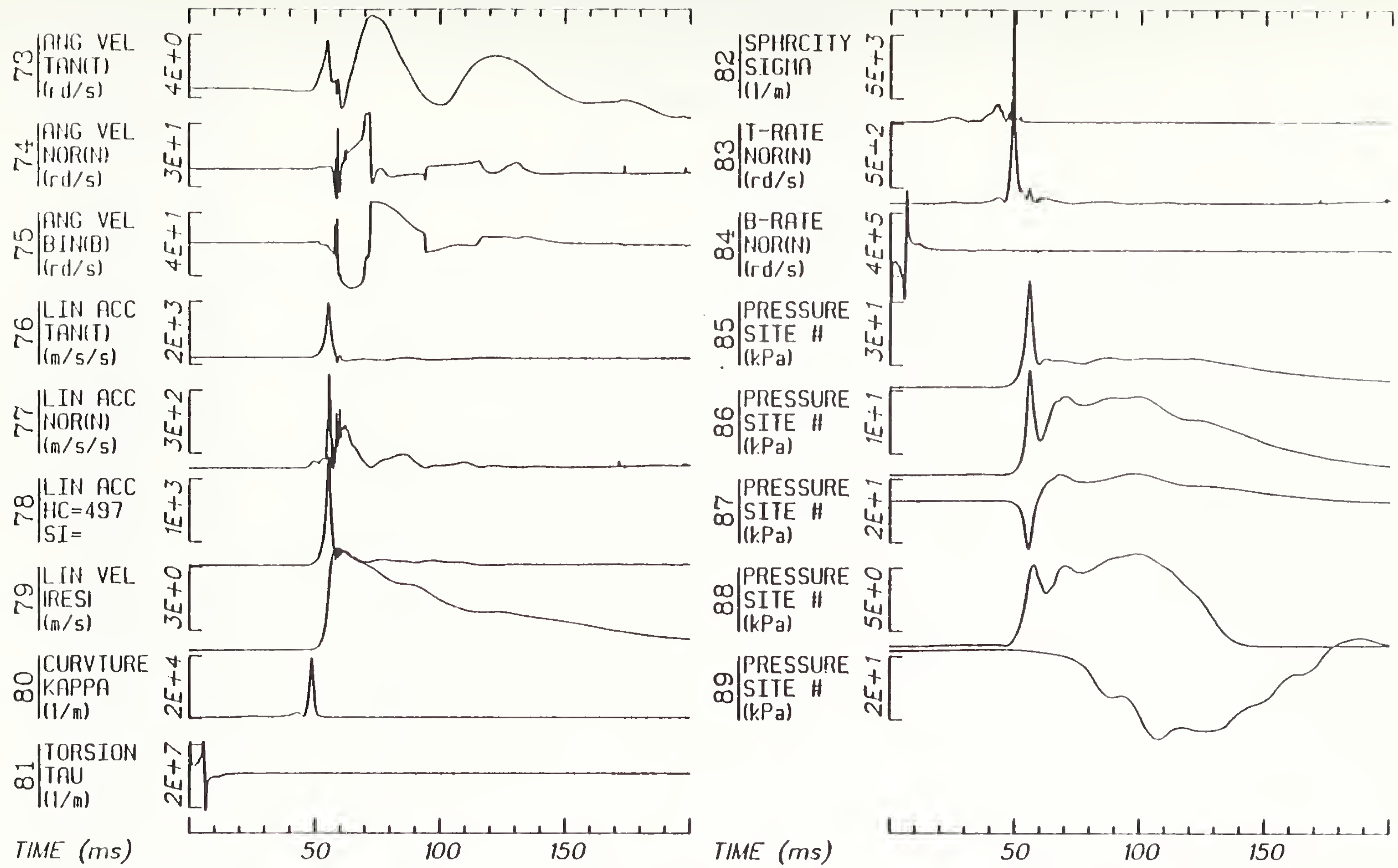
Run ID: 83E081 Disk: 83E081.3 File: 1 Date: APR 1, 1985 Sheet: 3

*Filter:1600*4C*



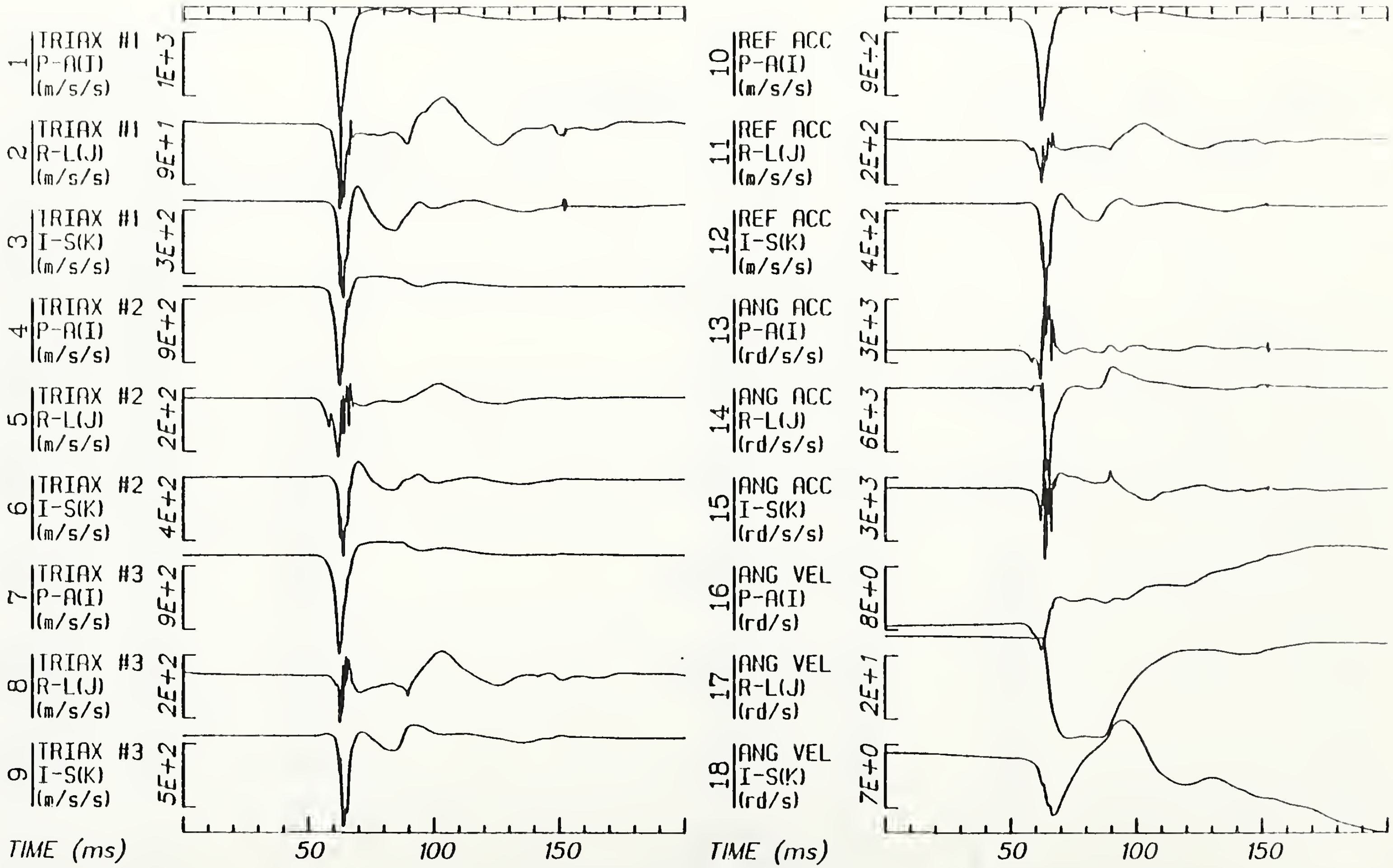
Run ID: 83E081 Disk: 83E081.3 File: 1 Date: APR 1, 1985 Sheet: 4

*Filter:1600*4C*



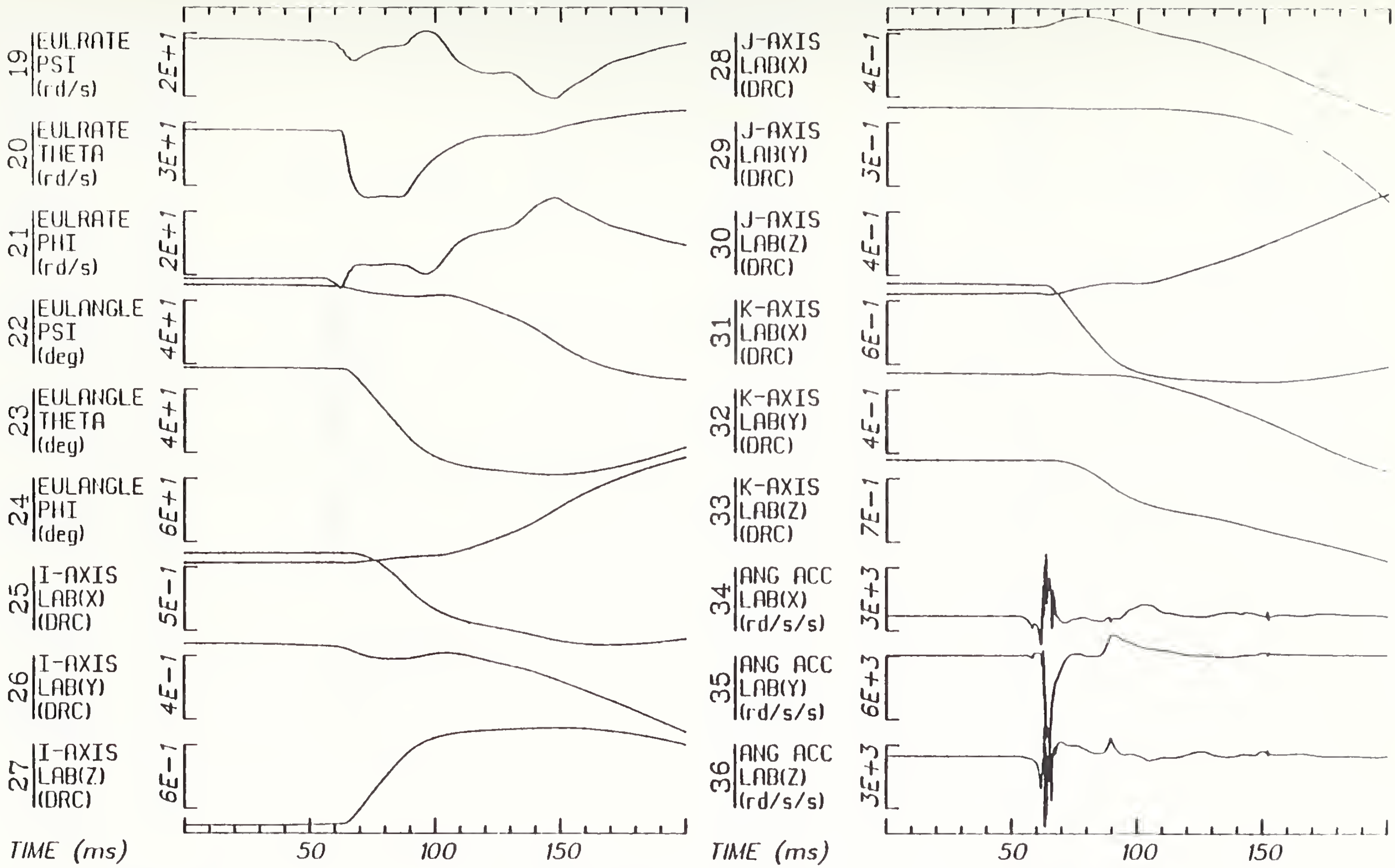
Run ID: 83E081 Disk: 83E081.3 File: 1 Date: APR 1, 1985 Sheet: 5

*Filter:1600*4C*



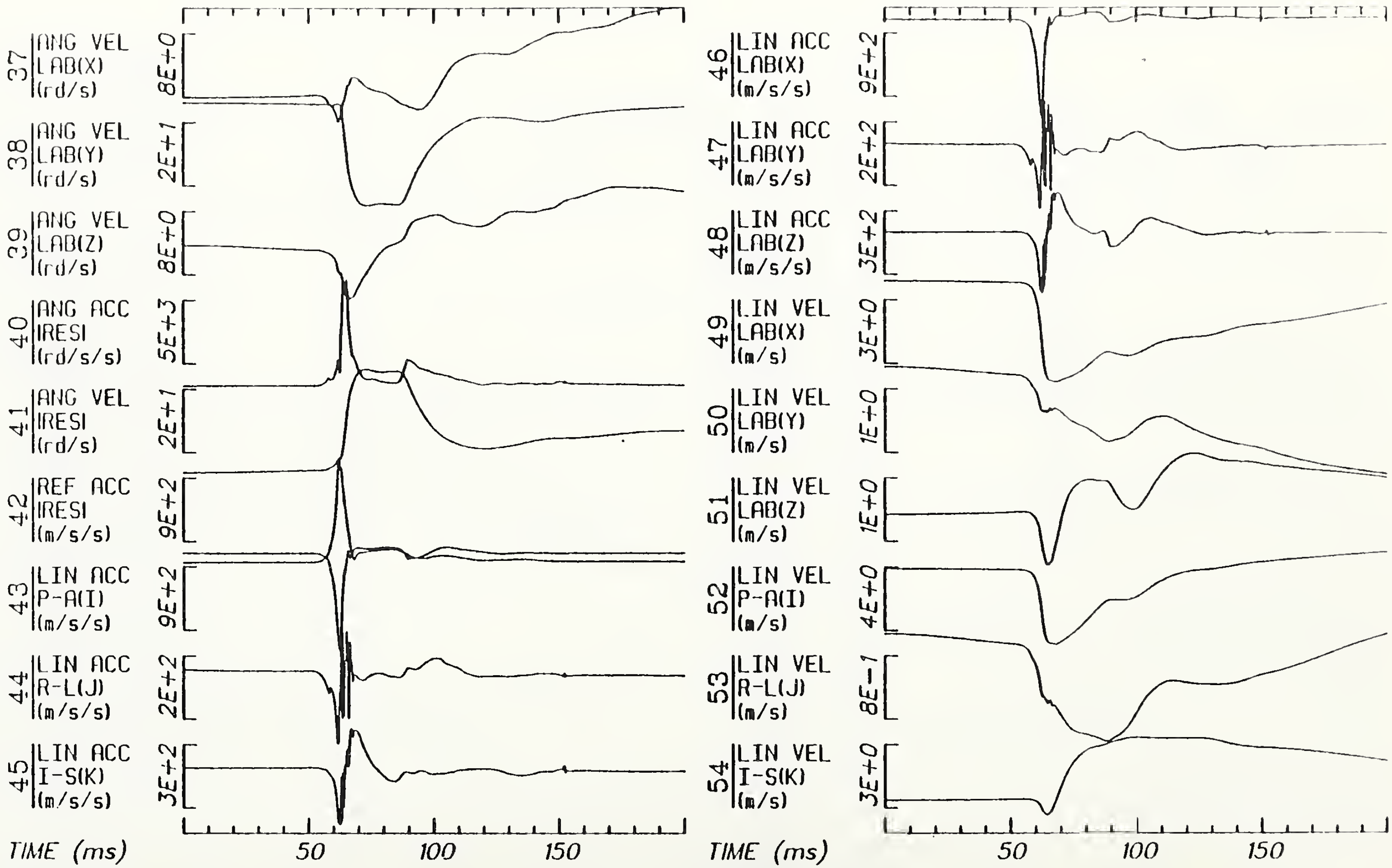
Run ID: 83E082 Disk: 83E082.3 File: 1 Date: APR 1, 1985 Sheet: 1

*Filter:1600*4C*



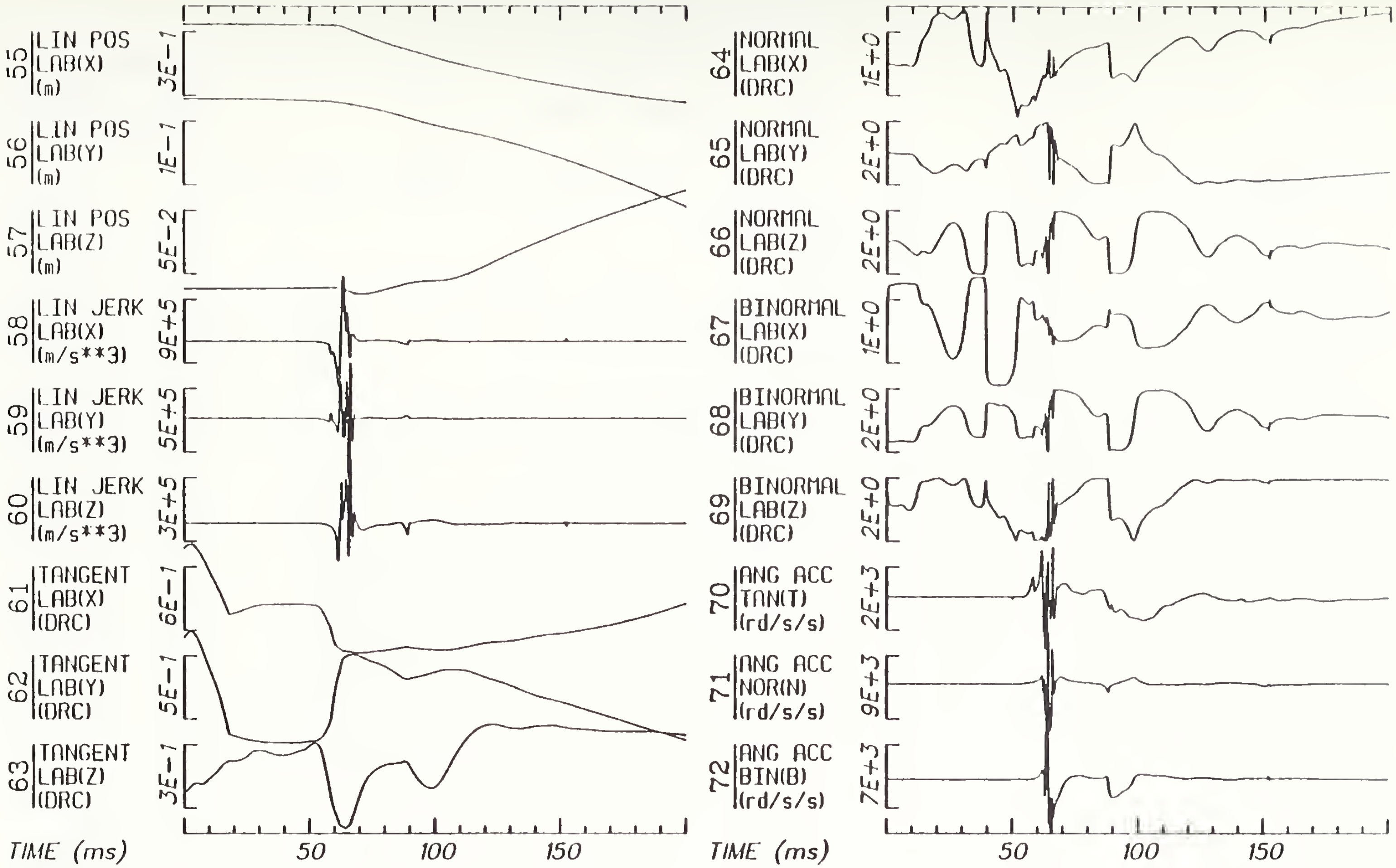
Run ID: 83E082 Disk: 83E082.3 File: 1 Date: APR 1, 1985 Sheet: 2

*Filter:1600*4C*



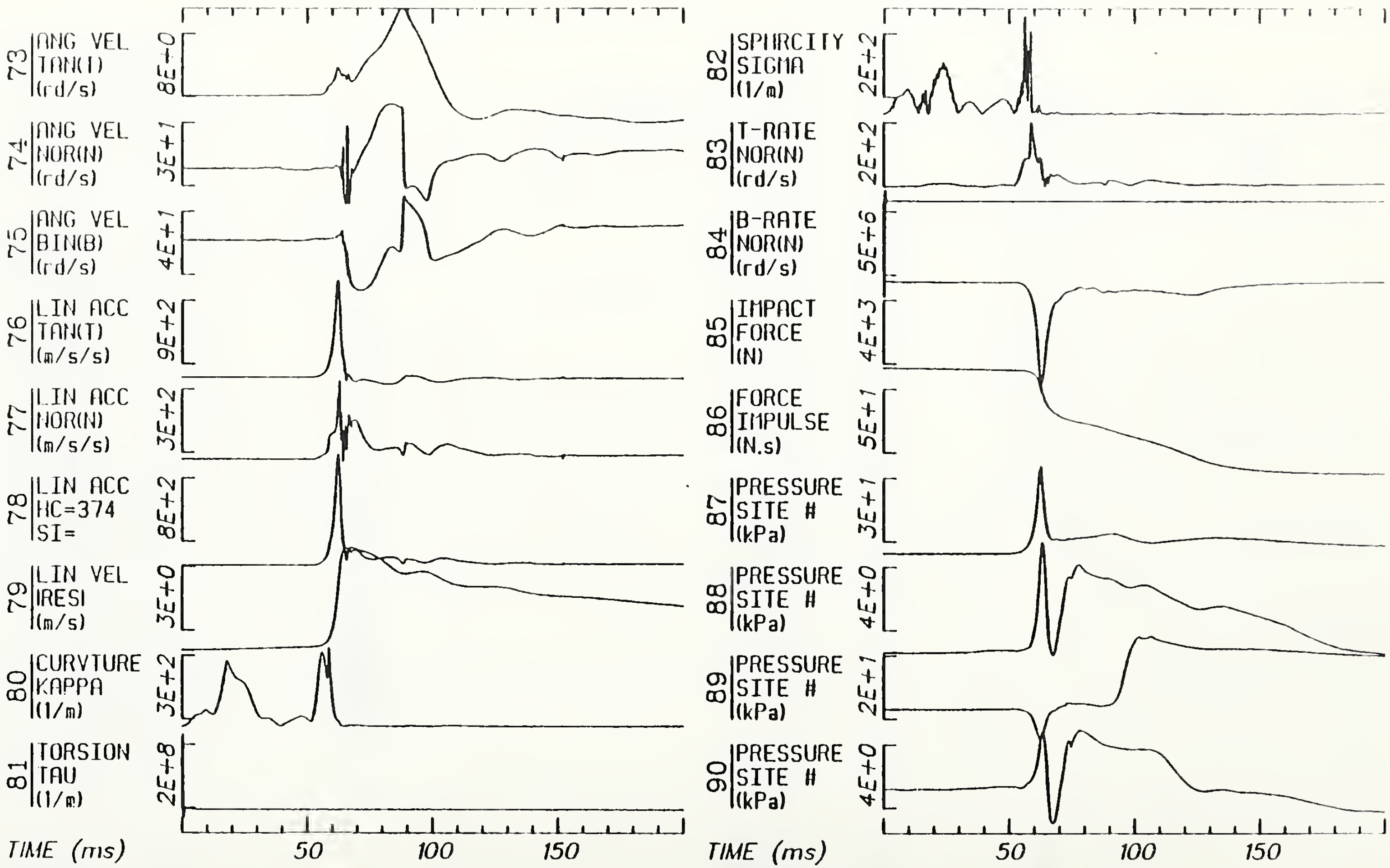
Run ID: 83E082 Disk: 83E082.3 File: 1 Date: APR 1, 1985 Sheet: 3

*Filter:1600*4C*



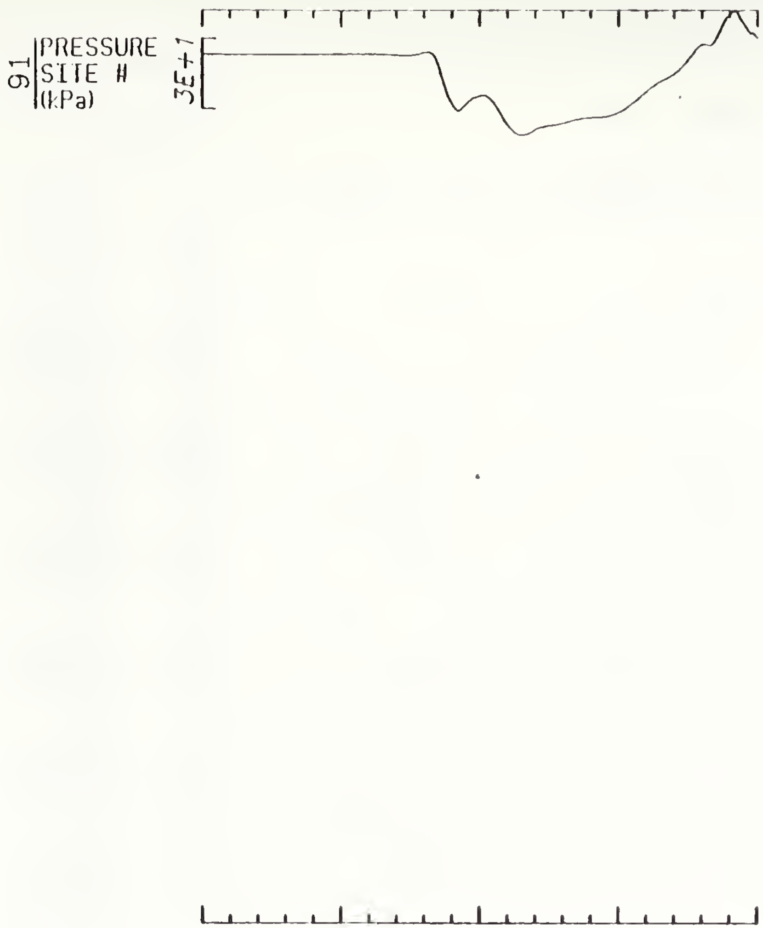
Run ID: 83E082 Disk: 83E082.3 File: 1 Date: APR 1, 1985 Sheet: 4

*Filter:1600*4C*



Run ID: 83E082 Disk: 83E082.3 File: 1 Date: APR 1, 1985 Sheet: 5

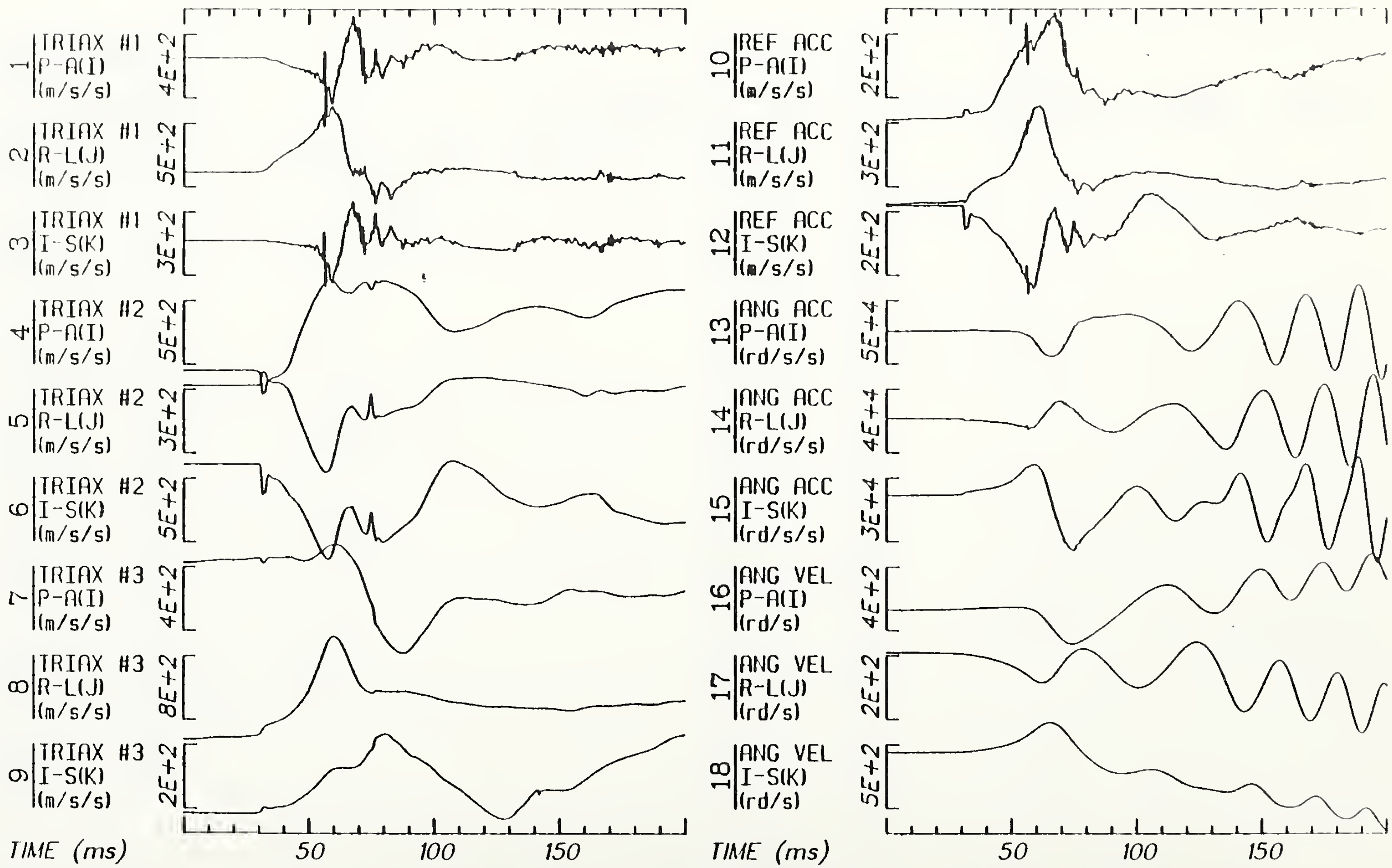
*Filter:1600*4C*



TIME (ms)

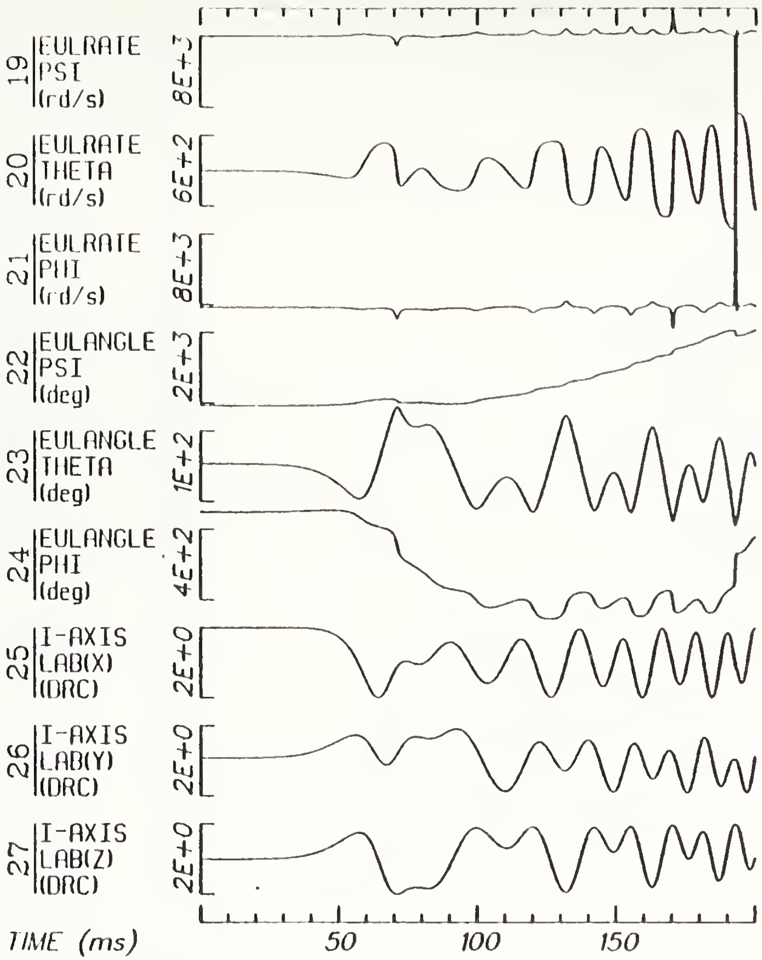
Run ID: 83E082 Disk: 83E082.3 File: 1 Date: APR 1, 1985 Sheet: 6

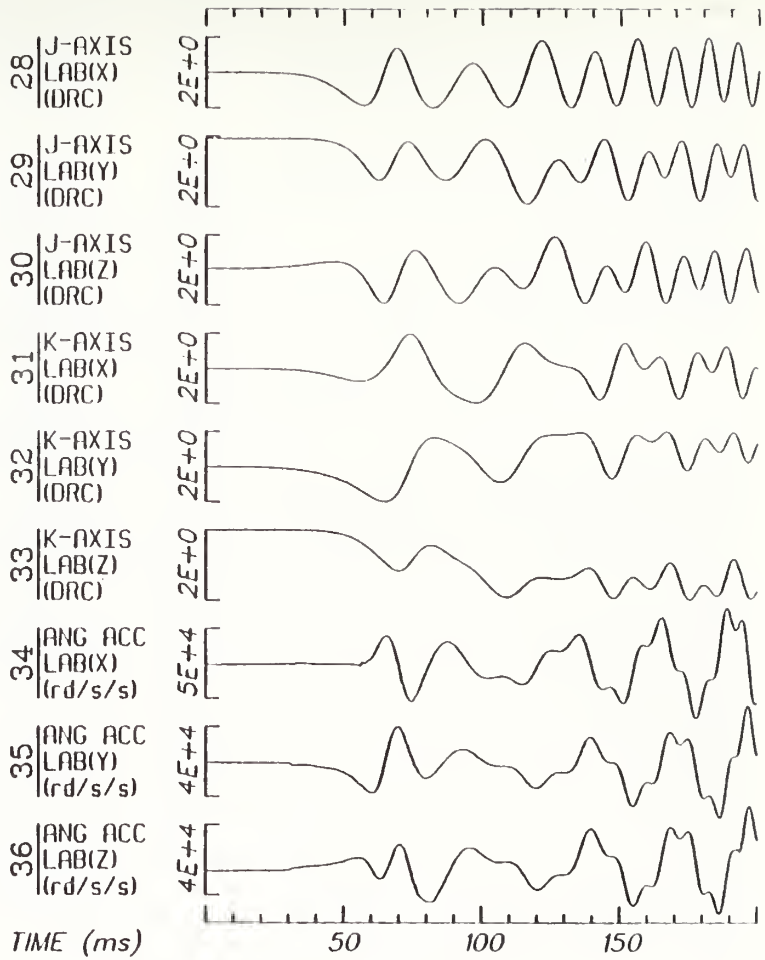
*Filter:1600*4C*



Run ID: 83E102 Disk: -HEAD File: 1 Date: MAR 12, 1985 Sheet: 1

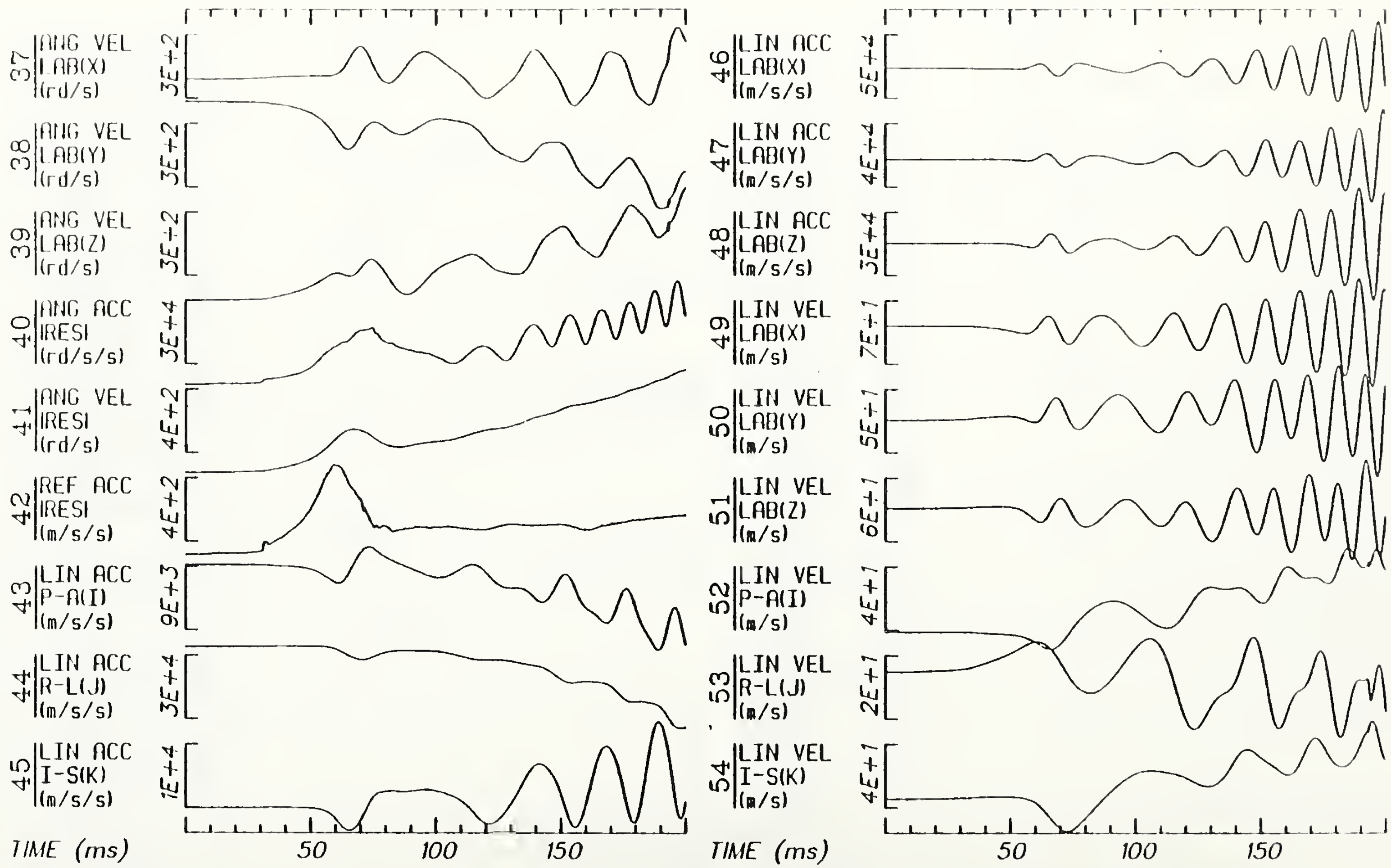
*Filter:1600*4C*





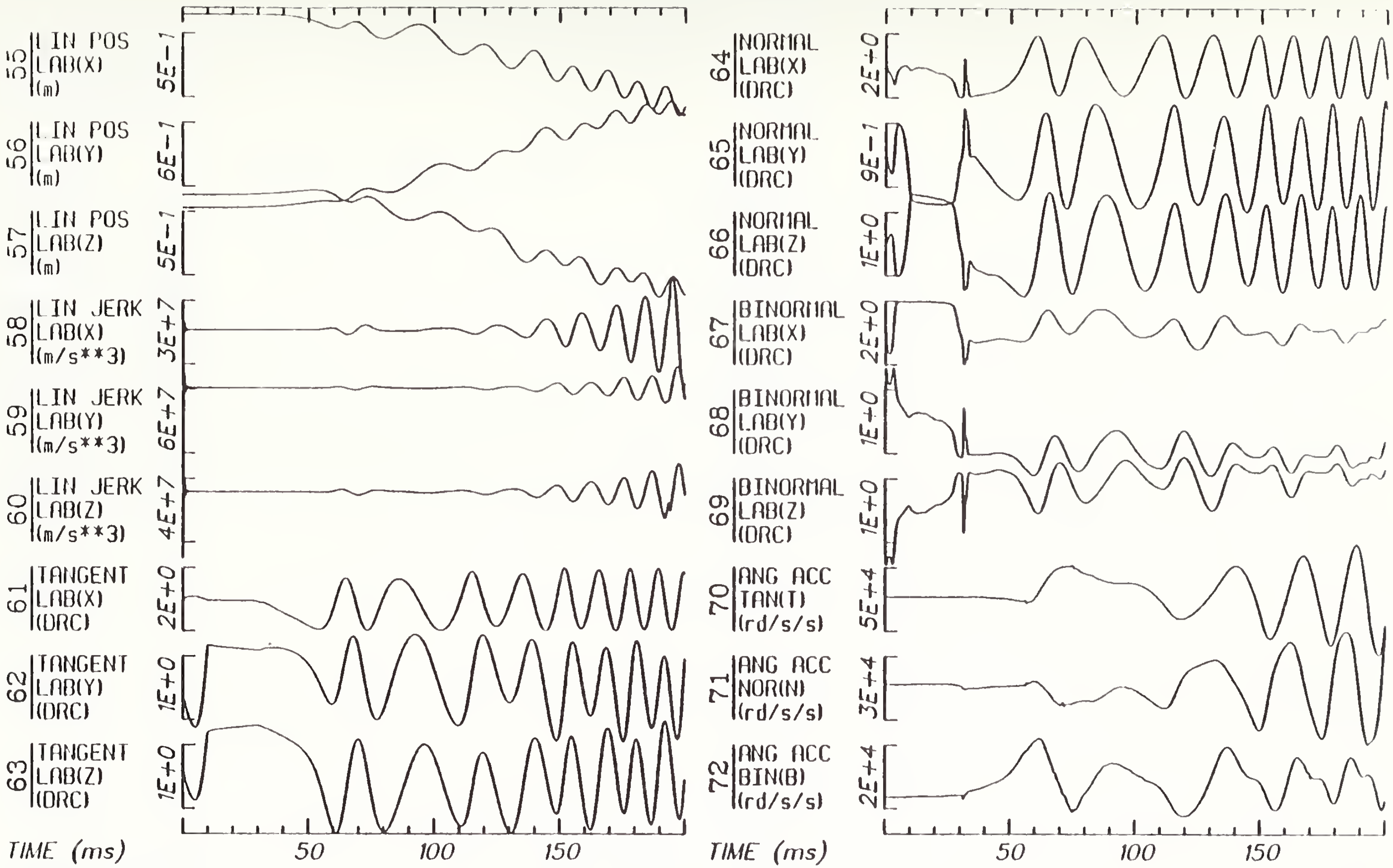
Run ID: 83E102 Disk: —HEAD File: 1 Date: MAR 12, 1985 Sheet: 2

*Filter:1600*4C*



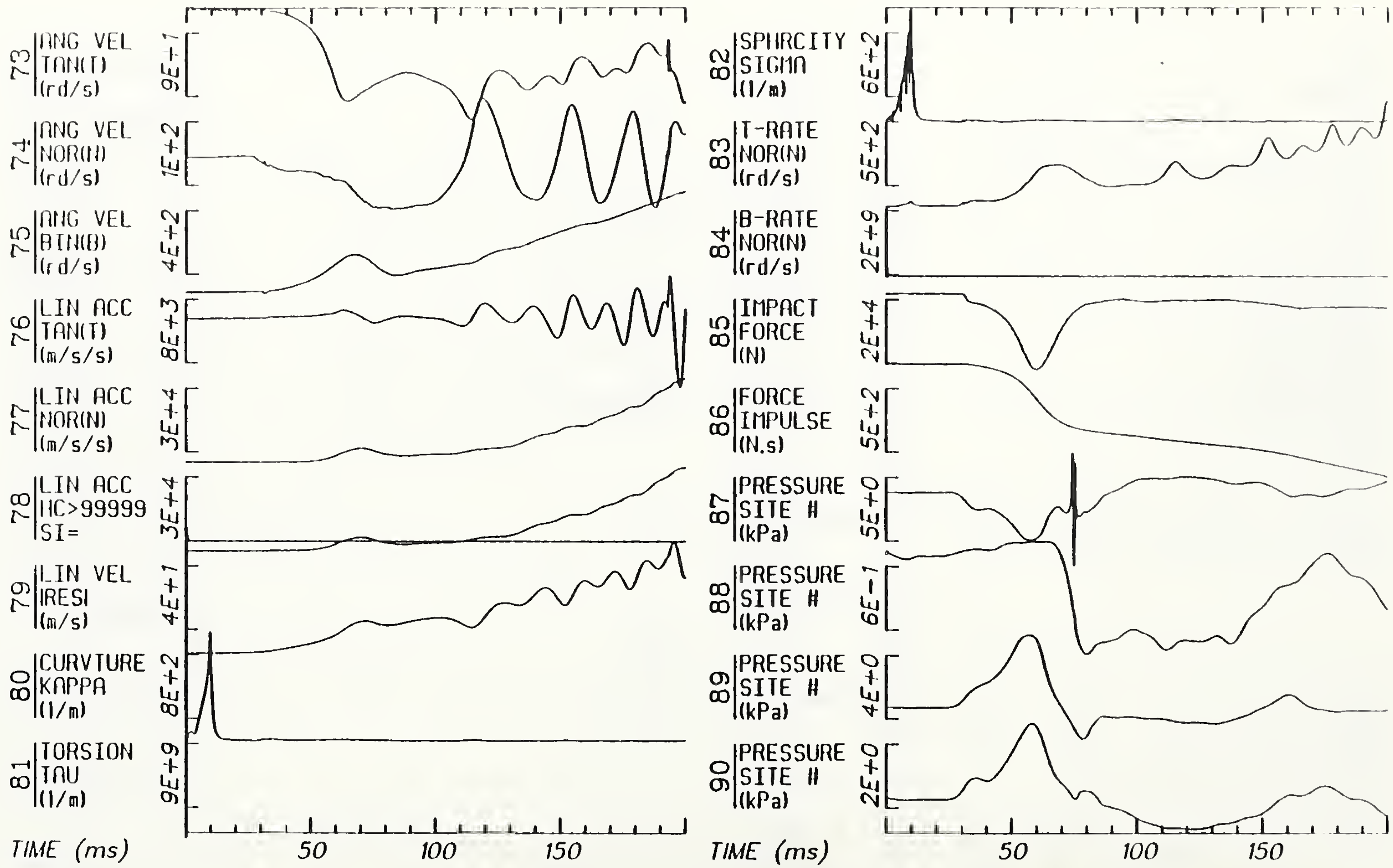
Run ID: 83E102 Disk: −HEAD File: 1 Date: MAR 12, 1985 Sheet: 3

*Filter:1600*4C*



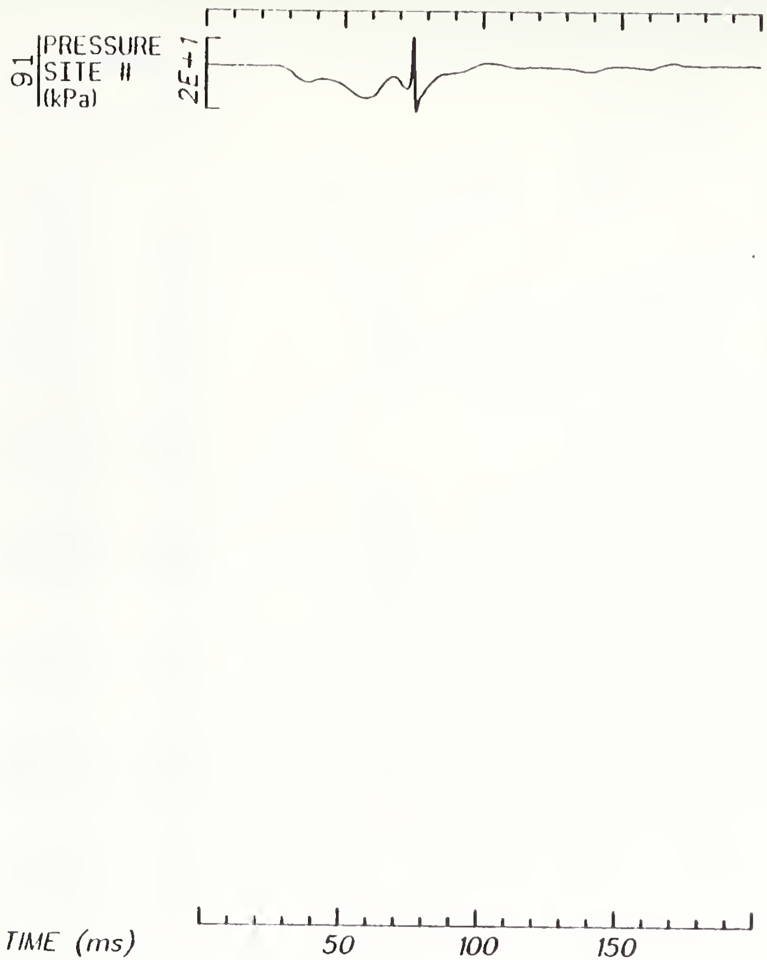
Run ID: 83E102 Disk: -HEAD File: 1 Date: MAR 12, 1985 Sheet: 4

*Filter:1600*4C*



Run ID: 83E102 Disk: -HEAD File: 1 Date: MAR 12, 1985 Sheet: 5

*Filter:1600*4C*



Run ID: 83E102

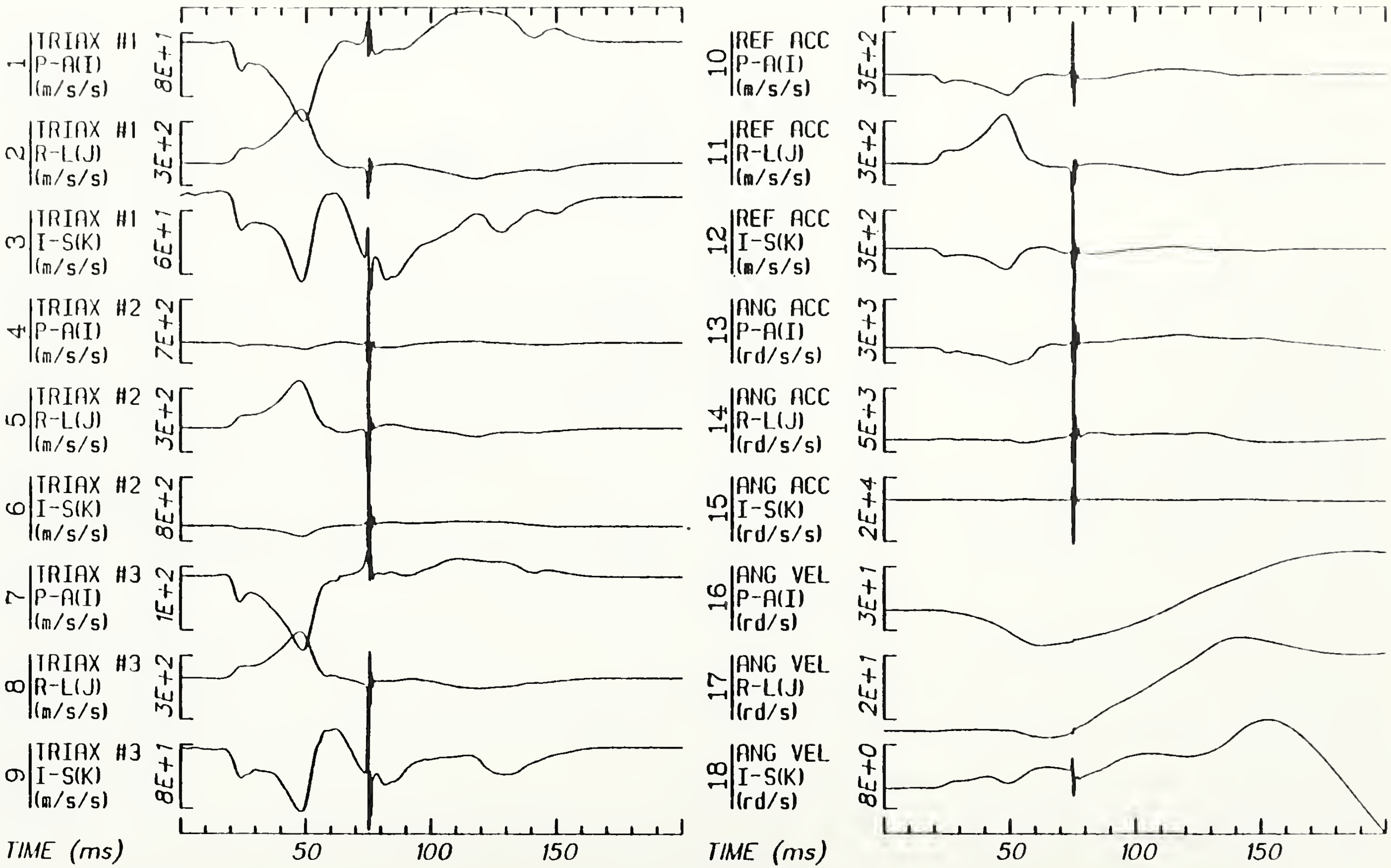
Disk: -HEAD

File: 1

Date: MAR 12, 1985

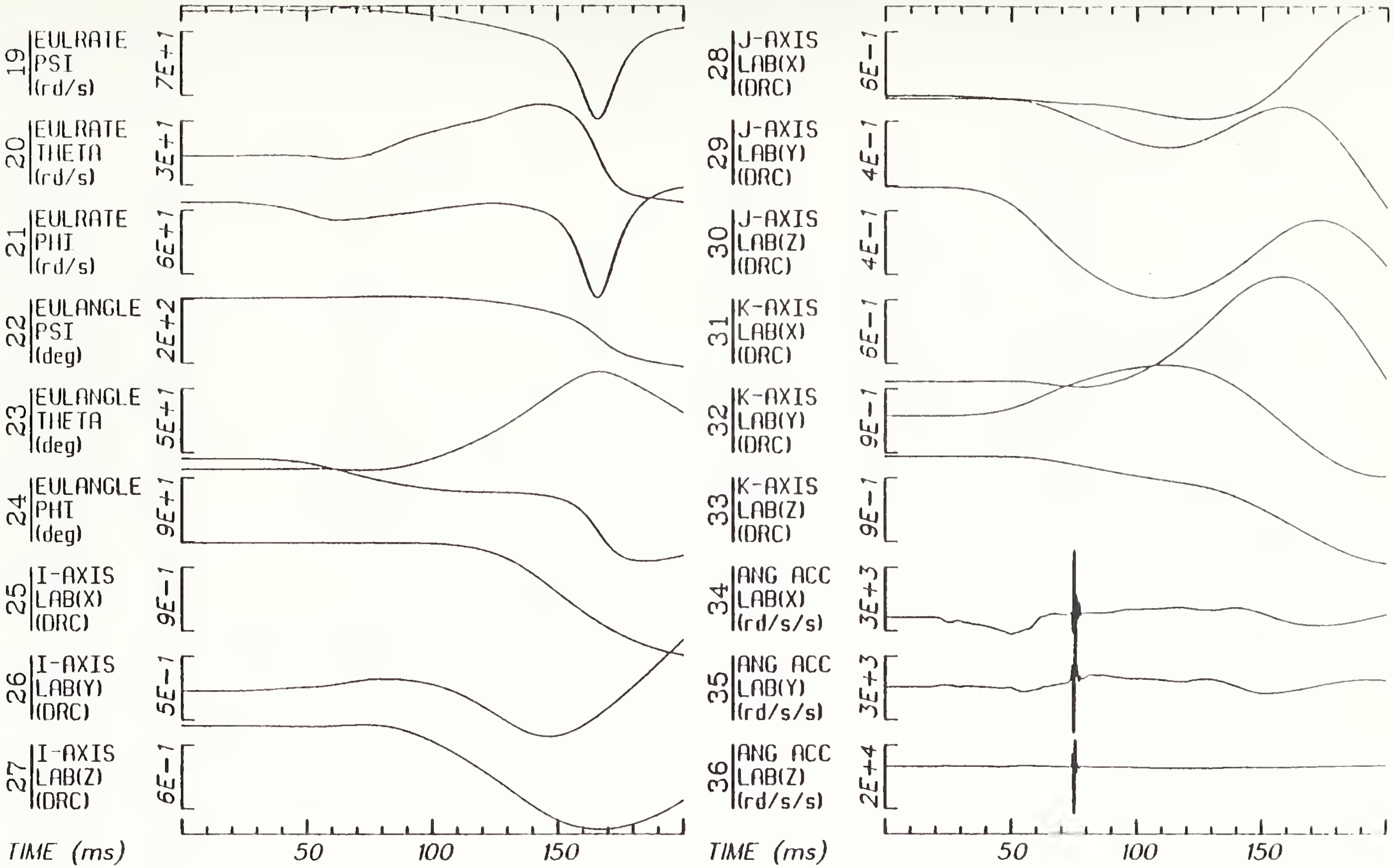
Sheet: 6

Filter:1600*4C



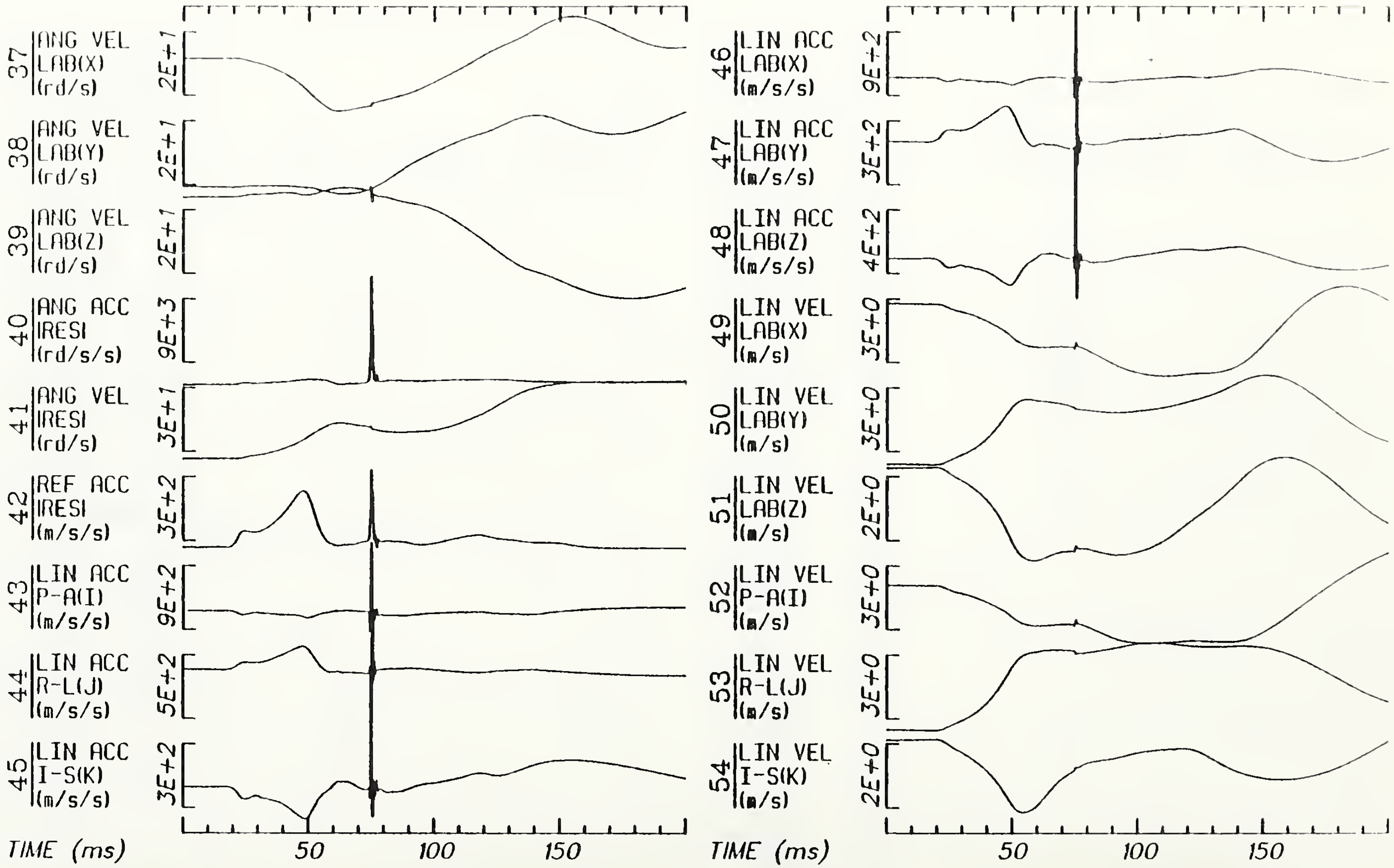
Run ID: 83E103 Disk: -HEAD File: 2 Date: MAR 12, 1985 Sheet: 1

Filter:1600*4C



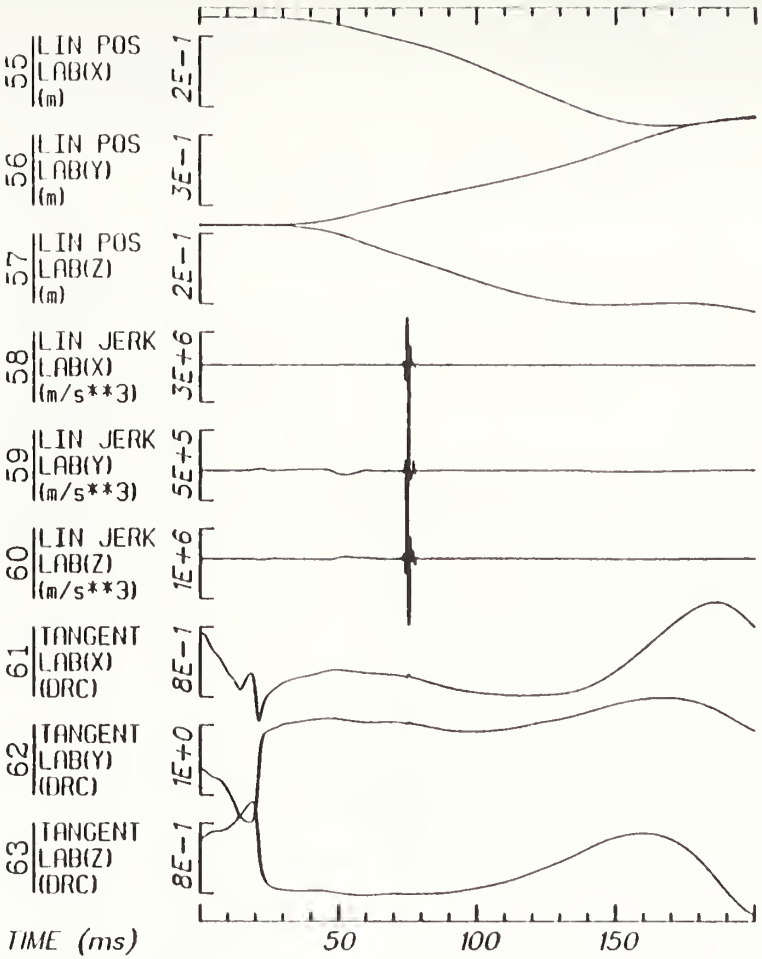
Run ID: 83E103 Disk: −HEAD File: 2 Date: MAR 12, 1985 Sheet: 2

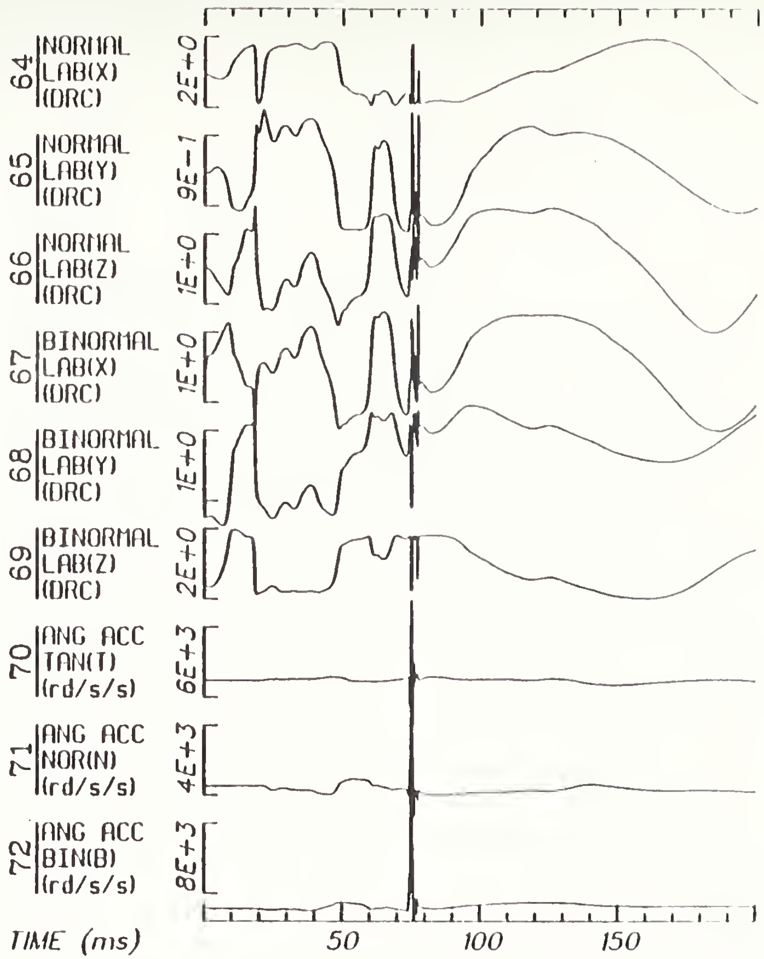
*Filter:1600*4C*



Run ID: 83E103 Disk: –HEAD File: 2 Date: MAR 12, 1985 Sheet: 3

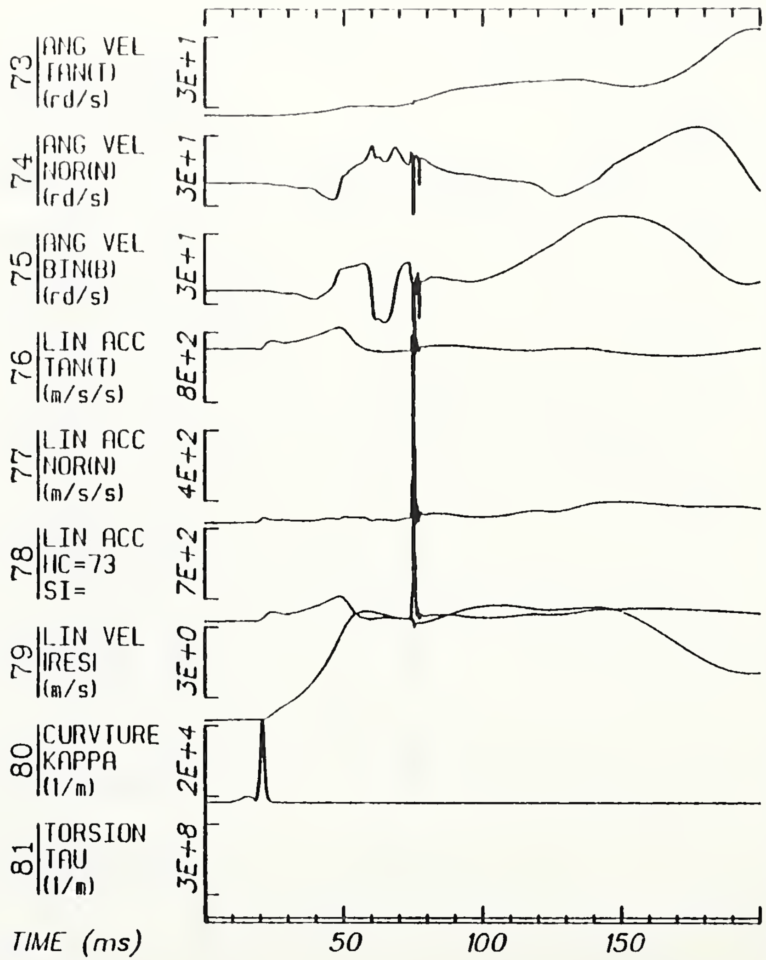
*Filter:1600*4C*

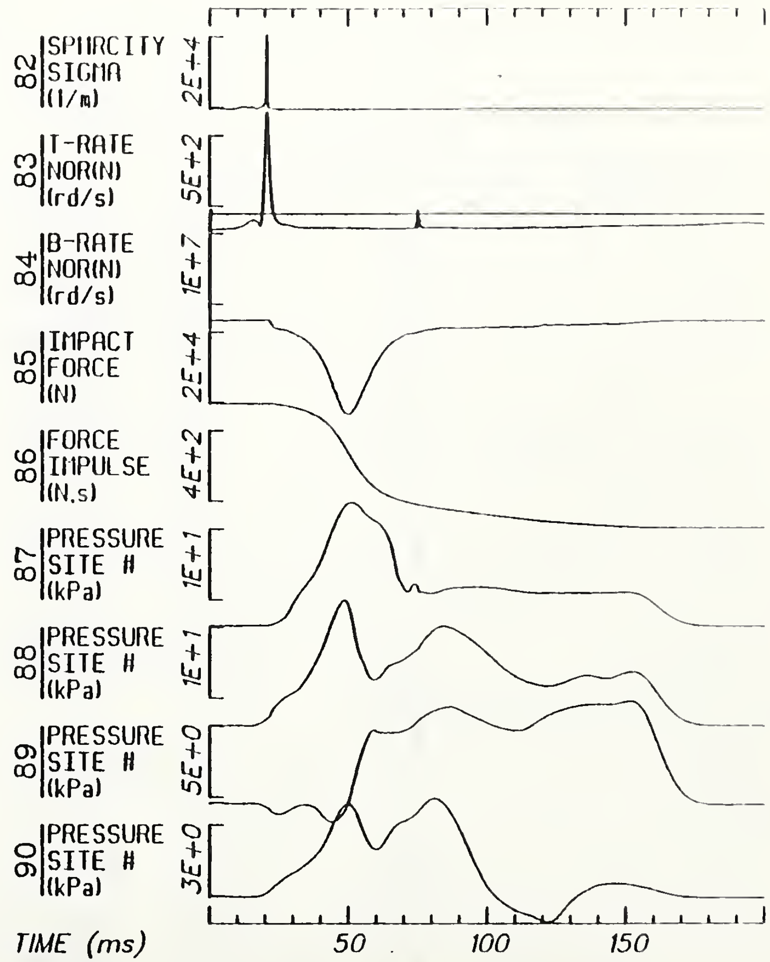




Run ID: 83E103 Disk: -HEAD File: 2 Date: MAR 12, 1985 Sheet: 4

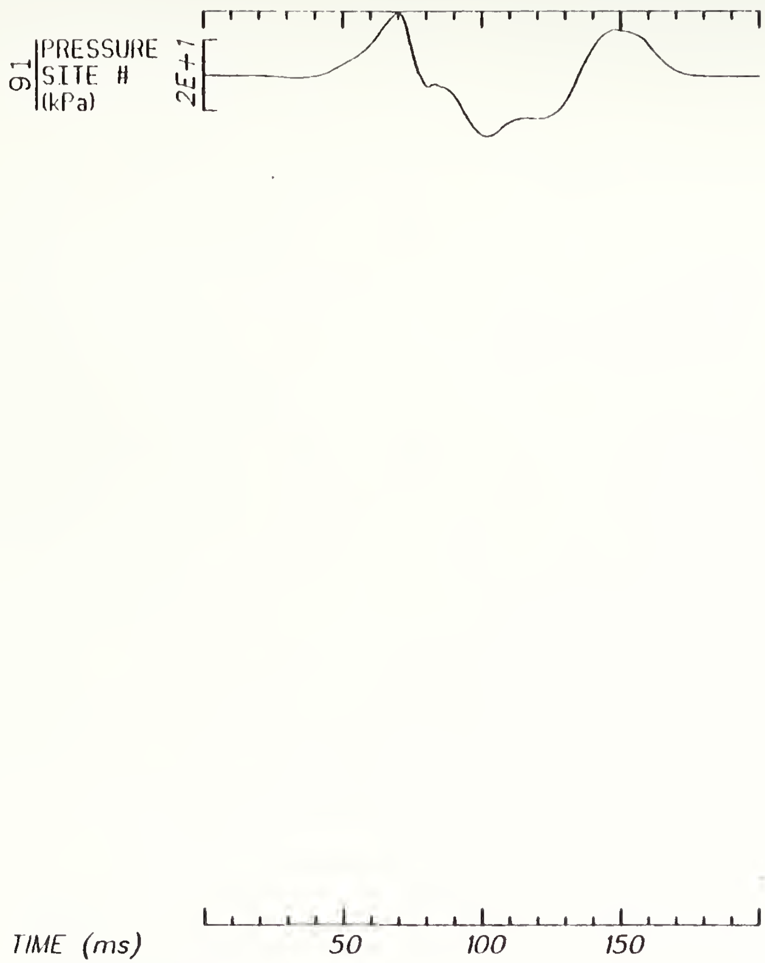
*Filter: 1600*4C*





Run ID: 83E103 Disk: -HEAD File: 2 Date: MAR 12, 1985 Sheet: 5

*Filter:1600*4C*



Run ID: 83E103 Disk: -HEAD File: 2 Date: MAR 12, 1985 Sheet: 6

*Filter: 1600*4C*

12.0 APPENDIX D: ANTHROPOMETRY

HUMAN SUBJECT INFORMATION

CADAVER NO.: 000 DURATION OF BED CONFINEMENT Unknown

AGE: 60 SEX: M CAUSE OF DEATH: Unknown

PHYSICAL APPEARANCE: Caucasian DATE OF DEATH: 3/21/82

ANOMALY: None

ANTHROPOMETRY

0 - Weight*	52 kg	
1 - Stature**	184cm	
2 - Shoulder (acromial) Height	159.4 cm	62.8 in
3 - Vertex to Symphysion Length	91.2 cm	35.9 in
4 - Waist Height	109.8 cm	43.2 in
5 - Shoulder Breadth (Biacromial Breadth)	31.8 cm	12.5 in
6 - Chest Breadth	27.9 cm	11 in
7 - Waist Breadth	29.2 cm	11.5 in
8 - Hip Breadth	25 cm	9.8 in
9 - Shoulder to Elbow Length (Acromion-radiale Length)	999	999
10 - Forearm-hand Length (elbow-middle finger)	999	999
11 - Tibiale Height	999	999
12 - Ankle Height (outside) (lateral malleous)	999	999
13 - Foot Breadth	999	999
14 - Foot Length	999	999

Note: * weight in kilograms

** lengths in centimeters

*** measures 16 and 17 must be made in case where the subject will be used in the seated position during the tests. In all other cases enter 9999 when under these measures.

LABORATORY UMTRI TEST NO. 82E001-3 82E004-7 82E008

15 - Top of Head to Trochanterion Length..........	88.5 cm	34.8 in
16 - Seated Height***..............................	999	999
17 - Knee Height (seated)***.......................	999	999
18 - Head Length...................................	19.7 cm	7.8 in
19 - Head Breadth..................................	15.7 cm	6.2 in
20 - Head to Chin Height (Vertex to Mentum).......	22.8 cm	9 in
21 - Biceps Circumference..........................	999	999
22 - Elbow Circumference...........................	999	999
23 - Forearm Circumference.........................	999	999
24 - Wrist Circumference...........................	999	999
25 - Thigh Circumference...........................	999	999
26 - Lower Thigh Circumference.....................	999	999
27 - Knee Circumference............................	999	999
28 - Calf Circumference............................	999	999
29 - Ankle Circumference...........................	999	999
30 - Neck Circumference............................	32.3cm	12.7 in
31 - Scye (armpit-shoulder) Circumference.........	999	999
32 - Chest Circumference...........................	79.3 cm	31.2 in
33 - Waist Circumference...........................	999	999
34 - Buttock Circumference.........................	999	999
35 - Chest Depth...................................	15.8 cm	6.2 in
36 - Waist Depth...................................	999	999
37 - Buttock Depth.................................	999	999
38 - Interscye.....................................	999	999

LABORATORY UMTRI TEST NO. 82E001-3 82E004-7 82E008

HUMAN SUBJECT INFORMATION

CADAVER NO.: 020 DURATION OF BED CONFINEMENT Unknown

AGE: 67 SEX: M CAUSE OF DEATH: Unknown

PHYSICAL APPEARANCE: Caucasian DATE OF DEATH: 3/23/82

ANOMALY: Excessive fat increased time required for spinal mounts

ANTHROPOMETRY

0 - Weight*	77 kg	
1 - Stature**	179.8 cm	
2 - Shoulder (acromial) Height	156 cm	61.4 in
3 - Vertex to Symphysion Length	88.5 cm	34.8 in
4 - Waist Height	107.3 cm	42.2 in
5 - Shoulder Breadth (Biacromial Breadth)	33.2 cm	13.1 in
6 - Chest Breadth	32.7 cm	12.9 in
7 - Waist Breadth	24 cm	9.4 in
8 - Hip Breadth	36 cm	14.2 in
9 - Shoulder to Elbow Length (Acromion-radiale Length)	999	999
10 - Forearm-hand Length (elbow-middle finger)	999	999
11 - Tibiale Height	999	999
12 - Ankle Height (outside) (lateral malleous)	999	999
13 - Foot Breadth	999	999
14 - Foot Length	999	999

Note: * weight in kilograms

** lengths in centimeters

*** measures 16 and 17 must be made in case where the subject will be used in the seated position during the tests. In all other cases enter 9999 when under these measures.

LABORATORY UMTRI D4 TEST NO. 82E021-22 82E023-27 82E028

15 - Top of Head to Trochanterion Length..........	999	999
16 - Seated Height***...........................	999	999
17 - Knee Height (seated)***....................	999	999
18 - Head Length................................	21 cm	8.2 in
19 - Head Breadth...............................	15.8 cm	6.2 in
20 - Head to Chin Height (Vertex to Mentum).......	24.9 cm	9.8 in
21 - Biceps Circumference.......................	999	999
22 - Elbow Circumference........................	999	999
23 - Forearm Circumference......................	999	999
24 - Wrist Circumference........................	999	999
25 - Thigh Circumference........................	999	999
26 - Lower Thigh Circumference..................	999	999
27 - Knee Circumference.........................	999	999
28 - Calf Circumference.........................	999	999
29 - Ankle Circumference........................	999	999
30 - Neck Circumference.........................	42 cm	16.5 in
31 - Scye (armpit-shoulder) Circumference.........	999	999
32 - Chest Circumference........................	99 cm	39 in
33 - Waist Circumference........................	999	999
34 - Buttock Circumference......................	999	999
35 - Chest Depth................................	22.2 cm	8.7 in
36 - Waist Depth................................	999	999
37 - Buttock Depth..............................	999	999
38 - Interscye..................................	999	999

LABORATORY UMTRI TEST NO. 82E021-22 82E023-27 82E028

HUMAN SUBJECT INFORMATION

CADAVER NO.: 040 DURATION OF BED CONFINEMENT Unknown

AGE: 65 SEX: M CAUSE OF DEATH: Myocardial infarction

PHYSICAL APPEARANCE: Caucasian DATE OF DEATH: 3/27/82

ANOMALY: Upper ribs very close together and embedded in deep fat.

ANTHROPOMETRY

0 - Weight*	87 kg	
1 - Stature**	169.2 cm	
2 - Shoulder (acromial) Height	146.7 cm	57.8 in
3 - Vertex to Symphysion Length	81.8 cm	32.2 in
4 - Waist Height	102 cm	40.2 in
5 - Shoulder Breadth (Biacromial Breadth)	35.4 cm	13.9 in
6 - Chest Breadth	32.7 cm	12.9 in
7 - Waist Breadth	32 cm	12.6 in
8 - Hip Breadth	33.5 cm	13.2 in
9 - Shoulder to Elbow Length (Acromion-radiale Length)	999	999
10 - Forearm-hand Length (elbow-middle finger)	999	999
11 - Tibiale Height	999	999
12 - Ankle Height (outside) (lateral malleous)	999	999
13 - Foot Breadth	999	999
14 - Foot Length	999	999

Note: * weight in kilograms

** lengths in centimeters

*** measures 16 and 17 must be made in case where the subject will be used in the seated position during the tests. In all other cases enter 9999 when under these measures.

LABORATORY UMTRI TEST NO. 82E041-42 82E043-48 82E049

15 - Top of Head to Trochanterion Length	999	999
16 - Seated Height***	999	999
17 - Knee Height (seated)***	999	999
18 - Head Length	20 cm	7.9 in
19 - Head Breadth	16.5 cm	6.5 in
20 - Head to Chin Height (Vertex to Mentum)	21.4 cm	8.4 in
21 - Biceps Circumference	999	999
22 - Elbow Circumference	999	999
23 - Forearm Circumference	999	999
24 - Wrist Circumference	999	999
25 - Thigh Circumference	999	999
26 - Lower Thigh Circumference	999	999
27 - Knee Circumference	999	999
28 - Calf Circumference	999	999
29 - Ankle Circumference	999	999
30 - Neck Circumference	50.4 cm	19.8 in
31 - Scye (armpit-shoulder) Circumference	999	999
32 - Chest Circumference	104.5 cm	41.1 in
33 - Waist Circumference	999	999
34 - Buttock Circumference	999	999
35 - Chest Depth	23.8 cm	9.4 in
36 - Waist Depth	999	999
37 - Buttock Depth	999	999
38 - Interscye	999	999

LABORATORY UMTRI TEST NO. 82E041-42 82E043-48 82E049

HUMAN SUBJECT INFORMATION

CADAVER NO.: 050 DURATION OF BED CONFINEMENT Unknown

AGE: 60 SEX: M CAUSE OF DEATH: Coronary thrombosis

PHYSICAL APPEARANCE: Caucasian DATE OF DEATH: 6/7/82

ANOMALY: Right and left ribs R4-R5 broken, probably from CPR.

ANTHROPOMETRY

0 - Weight*	67 kg	
1 - Stature**	180.2 cm	
2 - Shoulder (acromial) Height	155.7 cm	61.8 in
3 - Vertex to Symphysion Length	999	999
4 - Waist Height	999	999
5 - Shoulder Breadth (Biacromial Breadth)	37.5 cm	14.8 in
6 - Chest Breadth	999	999
7 - Waist Breadth	999	999
8 - Hip Breadth	999	999
9 - Shoulder to Elbow Length (Acromion-radiale Length)	999	999
10 - Forearm-hand Length (elbow-middle finger)	999	999
11 - Tibiale Height	999	999
12 - Ankle Height (outside) (lateral malleous)	999	999
13 - Foot Breadth	999	999
14 - Foot Length	999	999

Note: * weight in kilograms

** lengths in centimeters

*** measures 16 and 17 must be made in case where the subject will be used in the seated position during the tests. In all other cases enter 9999 when under these measures.

LABORATORY UMTRI D8 TEST NO. 82E051-53

15 - Top of Head to Trochanterion Length..........	999	999
16 - Seated Height***..........................	999	999
17 - Knee Height (seated)***......................	999	999
18 - Head Length..............................	20 cm	7.9 in
19 - Head Breadth.............................	16.2 cm	6.4 in
20 - Head to Chin Height (Vertex to Mentum).......	999	999
21 - Biceps Circumference......................	999	999
22 - Elbow Circumference.......................	999	999
23 - Forearm Circumference.....................	999	999
24 - Wrist Circumference.......................	999	999
25 - Thigh Circumference.......................	999	999
26 - Lower Thigh Circumference..................	999	999
27 - Knee Circumference........................	999	999
28 - Calf Circumference........................	999	999
29 - Ankle Circumference.......................	999	999
30 - Neck Circumference........................	40.5 cm	15.9 in
31 - Scye (armpit-shoulder) Circumference.........	999	999
32 - Chest Circumference.......................	999	999
33 - Waist Circumference.......................	999	999
34 - Buttock Circumference......................	999	999
35 - Chest Depth..............................	999	999
36 - Waist Depth..............................	999	999
37 - Buttock Depth............................	999	999
38 - Interscye................................	999	999

LABORATORY UMTRI TEST NO. 82E051-53

HUMAN SUBJECT INFORMATION

CADAVER NO.: 060 DURATION OF BED CONFINEMENT Unknown

AGE: 60 SEX: M CAUSE OF DEATH: Unknown

PHYSICAL APPEARANCE: Caucasian DATE OF DEATH: 6/1/82

ANOMALY: None

ANTHROPOMETRY

0 - Weight*	67 kg	
1 - Stature**	169.8 cm	
2 - Shoulder (acromial) Height	148.4 cm	58.4 in
3 - Vertex to Symphysion Length	86.1 cm	33.9 in
4 - Waist Height	99.8 cm	39.3 in
5 - Shoulder Breadth (Biacromial Breadth)	34.7 cm	13.7 in
6 - Chest Breadth	29.1 cm	11.5 in
7 - Waist Breadth	23 cm	9.1 in
8 - Hip Breadth	28.6 cm	11.3 in
9 - Shoulder to Elbow Length (Acromion-radiale Length)	999	999
10 - Forearm-hand Length (elbow-middle finger)	999	999
11 - Tibiale Height	999	999
12 - Ankle Height (outside) (lateral malleous)	999	999
13 - Foot Breadth	999	999
14 - Foot Length	999	999

Note: * weight in kilograms

** lengths in centimeters

*** measures 16 and 17 must be made in case where the subject will be used in the seated position during the tests. In all other cases enter 9999 when under these measures.

LABORATORY UMTRI DID ______ TEST NO. 82E061-62 82E063-66 82E067

15 - Top of Head to Trochanterion Length.........	999	999
16 - Seated Height***.............................	999	999
17 - Knee Height (seated)***.....................	999	999
18 - Head Length..................................	19.2 cm	7.6 in
19 - Head Breadth.................................	15.5 cm	6.1 in
20 - Head to Chin Height (Vertex to Mentum).......	22.1 cm	8.7 in
21 - Biceps Circumference.........................	999	999
22 - Elbow Circumference..........................	999	999
23 - Forearm Circumference........................	999	999
24 - Wrist Circumference..........................	999	999
25 - Thigh Circumference..........................	999	999
26 - Lower Thigh Circumference....................	999	999
27 - Knee Circumference...........................	999	999
28 - Calf Circumference...........................	999	999
29 - Ankle Circumference..........................	999	999
30 - Neck Circumference...........................	44.6 cm	17.6 in
31 - Scye (armpit-shoulder) Circumference.........	999	999
32 - Chest Circumference..........................	90.2 cm	35.5 in
33 - Waist Circumference..........................	999	999
34 - Buttock Circumference........................	999	999
35 - Chest Depth..................................	21.6 cm	8.5 in
36 - Waist Depth..................................	999	999
37 - Buttock Depth................................	999	999
38 - Interscye....................................	999	999

LABORATORY UMTRI TEST NO. 82E061-62 82E063-66 82E067

HUMAN SUBJECT INFORMATION

CADAVER NO.: 070 DURATION OF BED CONFINEMENT unknown

AGE: 61 SEX: M CAUSE OF DEATH: unknown

PHYSICAL APPEARANCE: Causian DATE OF DEATH: 9/9/82

ANOMALY:

Ribs broken during CPR attached to sternum with wire.

ANTHROPOMETRY

0 - Weight*....................................		55 kg
1 - Stature**..................................	181 cm	
2 - Shoulder (acromial) Height.................	156 cm	61.4 in
3 - Vertex to Symphysion Length................	999	999
4 - Waist Height...............................	999	999
5 - Shoulder Breadth (Biacromial Breadth)......	36.2 cm	14.3 in
6 - Chest Breadth..............................	999	999
7 - Waist Breadth..............................	999	999
8 - Hip Breadth................................	999	999
9 - Shoulder to Elbow Length (Acromion-radiale Length) ..	999	999
10 - Forearm-hand Length (elbow-middle finger)....	999	999
11 - Tibiale Height............................	999	999
12 - Ankle Height (outside) (lateral malleous)....	999	999
13 - Foot Breadth..............................	999	999
14 - Foot Length...............................	999	999

Note: * weight in kilograms

** lengths in centimeters

*** measures 16 and 17 must be made in case where the subject will be used in the seated position during the tests. In all other cases enter 9999 when under these measures.

LABORATORY UMTRI D12 ____ TEST NO. 82E071

15 - Top of Head to Trochanterion Length	999	999
16 - Seated Height***	999	999
17 - Knee Height (seated)***	999	999
18 - Head Length	20.6 cm	8.1 in
19 - Head Breadth	15.3 cm	6 in
20 - Head to Chin Height (Vertex to Mentum)	999	999
21 - Biceps Circumference	999	999
22 - Elbow Circumference	999	999
23 - Forearm Circumference	999	999
24 - Wrist Circumference	999	999
25 - Thigh Circumference	999	999
26 - Lower Thigh Circumference	999	999
27 - Knee Circumference	999	999
28 - Calf Circumference	999	999
29 - Ankle Circumference	999	999
30 - Neck Circumference	32 cm	12.6 in
31 - Scye (armpit-shoulder) Circumference	999	999
32 - Chest Circumference	999	999
33 - Waist Circumference	999	999
34 - Buttock Circumference	999	999
35 - Chest Depth	999	999
36 - Waist Depth	999	999
37 - Buttock Depth	999	999
38 - Interscye	999	999

LABORATORY UMTRI TEST NO. 82E071

HUMAN SUBJECT INFORMATION

CADAVER NO.: 079 DURATION OF BED CONFINEMENT Unknown

AGE: 51 SEX: M CAUSE OF DEATH: Myocardial infarction

PHYSICAL APPEARANCE: Caucasian DATE OF DEATH: 2/26/83

ANOMALY: Structures weakened from CPR.

ANTHROPOMETRY

0 - Weight*	83 kg	
1 - Stature**	169 cm	
2 - Shoulder (acromial) Height	146.5 cm	57.7 in
3 - Vertex to Symphysion Length	999	999
4 - Waist Height	999	999
5 - Shoulder Breadth (Biacromial Breadth)	30.4 cm	12 in
6 - Chest Breadth	34.2 cm	13.5 in
7 - Waist Breadth	999	999
8 - Hip Breadth	31 cm	12.2 in
9 - Shoulder to Elbow Length (Acromion-radiale Length)	999	999
10 - Forearm-hand Length (elbow-middle finger)	999	999
11 - Tibiale Height	999	999
12 - Ankle Height (outside) (lateral malleous)	999	999
13 - Foot Breadth	999	999
14 - Foot Length	999	999

Note: * weight in kilograms

** lengths in centimeters

*** measures 16 and 17 must be made in case where the subject will be used in the seated position during the tests. In all other cases enter 9999 when under these measures.

LABORATORY UMTRI D14 TEST NO. 83E076

15 - Top of Head to Trochanterion Length	999	999
16 - Seated Height***	999	999
17 - Knee Height (seated)***	999	999
18 - Head Length	20 cm	7.8 in
19 - Head Breadth	16 cm	6.3 in
20 - Head to Chin Height (Vertex to Mentum)	999	999
21 - Biceps Circumference	999	999
22 - Elbow Circumference	999	999
23 - Forearm Circumference	999	999
24 - Wrist Circumference	999	999
25 - Thigh Circumference	999	999
26 - Lower Thigh Circumference	999	999
27 - Knee Circumference	999	999
28 - Calf Circumference	999	999
29 - Ankle Circumference	999	999
30 - Neck Circumference	36 cm	14.2 in
31 - Scye (armpit-shoulder) Circumference	999	999
32 - Chest Circumference	999	999
33 - Waist Circumference	999	999
34 - Buttock Circumference	999	999
35 - Chest Depth	999	999
36 - Waist Depth	999	999
37 - Buttock Depth	999	999
38 - Interscye	999	999

LABORATORY UMTRI TEST NO. 83E076

HUMAN SUBJECT INFORMATION

CADAVER NO.: 080 DURATION OF BED CONFINEMENT Unknown

AGE: 44 SEX: M CAUSE OF DEATH: Pulmonary edema

PHYSICAL APPEARANCE: Caucasian DATE OF DEATH: 3/6/83

ANOMALY: Left rib R4 weakened. Sternum weakened.

ANTHROPOMETRY

0 - Weight*..................................	72 kg	
1 - Stature**..................................	171 cm	
2 - Shoulder (acromial) Height..................	147.4 cm	58 in
3 - Vertex to Symphysion Length.................	88 cm	34.6 in
4 - Waist Height................................	89.5 cm	35.2 in
5 - Shoulder Breadth (Biacromial Breadth)........	32.5 cm	12.8 in
6 - Chest Breadth...............................	33.8 cm	13.3 in
7 - Waist Breadth...............................	25 cm	9.8 in
8 - Hip Breadth.................................	31.4 cm	12.4 in
9 - Shoulder to Elbow Length (Acromion-radiale Length) ..	999	999
10 - Forearm-hand Length (elbow-middle finger)....	999	999
11 - Tibiale Height.............................	999	999
12 - Ankle Height (outside) (lateral malleous)....	999	999
13 - Foot Breadth...............................	999	999
14 - Foot Length................................	999	999

Note: * weight in kilograms

** lengths in centimeters

*** measures 16 and 17 must be made in case where the subject will be used in the seated position during the tests. In all other cases enter 9999 when under these measures.

LABORATORY UMTRI D16 TEST NO. 83E081-82 83E083-86 83E087-88

15 - Top of Head to Trochanterion Length	999	999
16 - Seated Height***	999	999
17 - Knee Height (seated)***	999	999
18 - Head Length	19.8 cm	7.8 in
19 - Head Breadth	15.5 cm	6.1 in
20 - Head to Chin Height (Vertex to Mentum)	23 cm	9.1 in
21 - Biceps Circumference	999	999
22 - Elbow Circumference	999	999
23 - Forearm Circumference	999	999
24 - Wrist Circumference	999	999
25 - Thigh Circumference	999	999
26 - Lower Thigh Circumference	999	999
27 - Knee Circumference	999	999
28 - Calf Circumference	999	999
29 - Ankle Circumference	999	999
30 - Neck Circumference	57 cm	22.4 in
31 - Scye (armpit-shoulder) Circumference	999	999
32 - Chest Circumference	100 cm	39.4 in
33 - Waist Circumference	999	999
34 - Buttock Circumference	999	999
35 - Chest Depth	15.3 cm	6 in
36 - Waist Depth	999	999
37 - Buttock Depth	999	999
38 - Interscye	999	999

LABORATORY UMTRI TEST NO. 83E081-82 83E083-86 83E087-88

HUMAN SUBJECT INFORMATION

CADAVER NO.: 089 DURATION OF BED CONFINEMENT Unknown

AGE: 62 SEX: M CAUSE OF DEATH: Myocardial infarction

PHYSICAL APPEARANCE: Caucasian DATE OF DEATH: 1/26/83

ANOMALY: None

ANTHROPOMETRY

0 -	Weight*	76 kg	
1 -	Stature**	175.8 cm	
2 -	Shoulder (acromial) Height	152 cm	59.8 in
3 -	Vertex to Symphysion Length	84.5 cm	33.3 in
4 -	Waist Height	999	999
5 -	Shoulder Breadth (Biacromial Breadth)	34.7 cm	13.7 in
6 -	Chest Breadth	34 cm	13.4 in
7 -	Waist Breadth	999	999
8 -	Hip Breadth	31.5 cm	12.4 in
9 -	Shoulder to Elbow Length (Acromion-radiale Length)	999	999
10 -	Forearm-hand Length (elbow-middle finger)	999	999
11 -	Tibiale Height	999	999
12 -	Ankle Height (outside) (lateral malleous)	999	999
13 -	Foot Breadth	999	999
14 -	Foot Length	999	999

Note: * weight in kilograms

** lengths in centimeters

*** measures 16 and 17 must be made in case where the subject will be used in the seated position during the tests. In all other cases enter 9999 when under these measures.

LABORATORY UMTRI D18 TEST NO. 83E071-75 83E091

15 - Top of Head to Trochanterion Length..........	999	999
16 - Seated Height***..............................	999	999
17 - Knee Height (seated)***......................	999	999
18 - Head Length..................................	19.0 cm	7.5 in
19 - Head Breadth.................................	15.3 cm	6 in
20 - Head to Chin Height (Vertex to Mentum).......	999	999
21 - Biceps Circumference.........................	999	999
22 - Elbow Circumference..........................	999	999
23 - Forearm Circumference........................	999	999
24 - Wrist Circumference..........................	999	999
25 - Thigh Circumference..........................	999	999
26 - Lower Thigh Circumference....................	999	999
27 - Knee Circumference...........................	999	999
28 - Calf Circumference...........................	999	999
29 - Ankle Circumference..........................	999	999
30 - Neck Circumference...........................	37 cm	14.6 in
31 - Scye (armpit-shoulder) Circumference.........	999	999
32 - Chest Circumference..........................	999	999
33 - Waist Circumference..........................	999	999
34 - Buttock Circumference........................	999	999
35 - Chest Depth..................................	999	999
36 - Waist Depth..................................	999	999
37 - Buttock Depth................................	999	999
38 - Interscye....................................	999	999

LABORATORY UMTRI TEST NO. 83E071-75 83E091

HUMAN SUBJECT INFORMATION

CADAVER NO.: 090 DURATION OF BED CONFINEMENT Unknown

AGE: 51 SEX: M CAUSE OF DEATH: Cerebral Contusion

PHYSICAL APPEARANCE: Caucasian DATE OF DEATH:

ANOMALY: None

ANTHROPOMETRY

0 - Weight*	68 kg	
1 - Stature**	180 cm	
2 - Shoulder (acromial) Height	155.4 cm	61.2 in
3 - Vertex to Symphysion Length	999	999
4 - Waist Height	999	999
5 - Shoulder Breadth (Biacromial Breadth)	33.3 cm	13.1 in
6 - Chest Breadth	31.9 cm	12.6 in
7 - Waist Breadth	999	999
8 - Hip Breadth	30 cm	11.8 in
9 - Shoulder to Elbow Length (Acromion-radiale Length)	999	999
10 - Forearm-hand Length (elbow-middle finger)	999	999
11 - Tibiale Height	999	999
12 - Ankle Height (outside) (lateral malleous)	999	999
13 - Foot Breadth	999	999
14 - Foot Length	999	999

Note: * weight in kilograms

** lengths in centimeters

*** measures 16 and 17 must be made in case where the subject will be used in the seated position during the tests. In all other cases enter 9999 when under these measures.

LABORATORY UMTRI TEST NO. 83E092 83E093

15 - Top of Head to Trochanterion Length..........	999	999
16 - Seated Height***............................	999	999
17 - Knee Height (seated)***.....................	999	999
18 - Head Length.................................	19.4 cm	7.6 in
19 - Head Breadth................................	15.5 cm	6.1 in
20 - Head to Chin Height (Vertex to Mentum).......	999	999
21 - Biceps Circumference........................	999	999
22 - Elbow Circumference.........................	999	999
23 - Forearm Circumference.......................	999	999
24 - Wrist Circumference.........................	999	999
25 - Thigh Circumference.........................	999	999
26 - Lower Thigh Circumference...................	999	999
27 - Knee Circumference..........................	999	999
28 - Calf Circumference..........................	999	999
29 - Ankle Circumference.........................	999	999
30 - Neck Circumference..........................	37 cm	14.6 in
31 - Scye (armpit-shoulder) Circumference.........	999	999
32 - Chest Circumference.........................	999	999
33 - Waist Circumference.........................	999	999
34 - Buttock Circumference.......................	999	999
35 - Chest Depth.................................	999	999
36 - Waist Depth.................................	999	999
37 - Buttock Depth...............................	999	999
38 - Interscye...................................	999	999

LABORATORY UMTRI TEST NO. 83E092 83E093

HUMAN SUBJECT INFORMATION

CADAVER NO.: 100 DURATION OF BED CONFINEMENT Unknown

AGE: 60 SEX: M CAUSE OF DEATH: Cardiac arrest - Carcinoma of Pancrea

PHYSICAL APPEARANCE: Caucasian DATE OF DEATH: 5/20/83

ANOMALY: Right rib R7 is abnormal.

ANTHROPOMETRY

0 - Weight*	76.5 kg	
1 - Stature**	182.3 cm	
2 - Shoulder (acromial) Height	158.5 cm	62.4 in
3 - Vertex to Symphysion Length	91.7 cm	36.1 in
4 - Waist Height	108.6 cm	42.8 in
5 - Shoulder Breadth (Biacromial Breadth)	31.4 cm	12.4 in
6 - Chest Breadth	27 cm	10.6 in
7 - Waist Breadth	31.3 cm	12.3 in
8 - Hip Breadth	33.9 cm	13.3 in
9 - Shoulder to Elbow Length (Acromion-radiale Length)	999	999
10 - Forearm-hand Length (elbow-middle finger)	999	999
11 - Tibiale Height	999	999
12 - Ankle Height (outside) (lateral malleous)	999	999
13 - Foot Breadth	999	999
14 - Foot Length	999	999

Note: * weight in kilograms

** lengths in centimeters

*** measures 16 and 17 must be made in case where the subject will be used in the seated position during the tests. In all other cases enter 9999 when under these measures.

LABORATORY UMTRI D22 TEST NO. 83E101-103 83E104-108 83E109

15 - Top of Head to Trochanterion Length..........	999	999
16 - Seated Height***..............................	999	999
17 - Knee Height (seated)***.......................	999	999
18 - Head Length...................................	19.3 cm	7.6 in
19 - Head Breadth..................................	14.6 cm	5.7 in
20 - Head to Chin Height (Vertex to Mentum).......	21.8 cm	8.6 in
21 - Biceps Circumference.........................	999	999
22 - Elbow Circumference..........................	999	999
23 - Forearm Circumference........................	999	999
24 - Wrist Circumference..........................	999	999
25 - Thigh Circumference..........................	999	999
26 - Lower Thigh Circumference....................	999	999
27 - Knee Circumference...........................	999	999
28 - Calf Circumference...........................	999	999
29 - Ankle Circumference..........................	999	999
30 - Neck Circumference...........................	38.3 cm	15.1 in
31 - Scye (armpit-shoulder) Circumference.........	999	999
32 - Chest Circumference..........................	91.7 cm	36.1 in
33 - Waist Circumference..........................	999	999
34 - Buttock Circumference........................	999	999
35 - Chest Depth..................................	22.5 cm	8.9 in
36 - Waist Depth..................................	999	999
37 - Buttock Depth................................	999	999
38 - Interscye....................................	999	999

LABORATORY UMTRI TEST NO. 83E101-103 83E104-108 83E109

HUMAN SUBJECT INFORMATION

CADAVER NO.: 120 DURATION OF BED CONFINEMENT Unknown

AGE: 20 SEX: F CAUSE OF DEATH: Renal failure

PHYSICAL APPEARANCE: Negro DATE OF DEATH: 8/22/83

ANOMALY: Sores on skin probably from needle punctures.

ANTHROPOMETRY

0 - Weight*	46 kg	
1 - Stature**	162.7 cm	
2 - Shoulder (acromial) Height	141.6 cm	55.7 in
3 - Vertex to Symphysion Length	76.3 cm	30 in
4 - Waist Height	99.2 cm	39.1 in
5 - Shoulder Breadth (Biacromial Breadth)	31 cm	12.2 in
6 - Chest Breadth	25.7 cm	10.1 in
7 - Waist Breadth	21.9 cm	8.6 in
8 - Hip Breadth	27.2 cm	10.7 in
9 - Shoulder to Elbow Length (Acromion-radiale Length)	999	999
10 - Forearm-hand Length (elbow-middle finger)	999	999
11 - Tibiale Height	999	999
12 - Ankle Height (outside) (lateral malleous)	999	999
13 - Foot Breadth	999	999
14 - Foot Length	999	999

Note: * weight in kilograms

** lengths in centimeters

*** measures 16 and 17 must be made in case where the subject will be used in the seated position during the tests. In all other cases enter 9999 when under these measures.

LABORATORY UMTRI D24 TEST NO. 83E121A-C

15 - Top of Head to Trochanterion Length..........	72.9 cm	28.7 in
16 - Seated Height***..............................	999	999
17 - Knee Height (seated)***......................	999	999
18 - Head Length..................................	18.9 cm	7.4 in
19 - Head Breadth.................................	14.4 cm	5.7 in
20 - Head to Chin Height (Vertex to Mentum).......	24.5 cm	9.6 in
21 - Biceps Circumference.........................	999	999
22 - Elbow Circumference..........................	999	999
23 - Forearm Circumference........................	999	999
24 - Wrist Circumference..........................	999	999
25 - Thigh Circumference..........................	999	999
26 - Lower Thigh Circumference....................	999	999
27 - Knee Circumference...........................	999	999
28 - Calf Circumference...........................	999	999
29 - Ankle Circumference..........................	999	999
30 - Neck Circumference...........................	32 cm	12.6 in
31 - Scye (armpit-shoulder) Circumference.........	999	999
32 - Chest Circumference..........................	71.4 cm	28.1 in
33 - Waist Circumference..........................	999	999
34 - Buttock Circumference........................	999	999
35 - Chest Depth..................................	17.6 cm	6.9 in
36 - Waist Depth..................................	999	999
37 - Buttock Depth................................	999	999
38 - Interscye....................................	999	999

LABORATORY UMTRI TEST NO. 83E121A-C

HUMAN SUBJECT INFORMATION

CADAVER NO.: 130 DURATION OF BED CONFINEMENT Unknown

AGE: 57 SEX: M CAUSE OF DEATH: Acute myocardial infarction

PHYSICAL APPEARANCE: Caucasian DATE OF DEATH: 9/11/83

ANOMALY: Autopsy revealed evidence of previous thoracic surgery. Ribs weakened at cartilaginous junction.

ANTHROPOMETRY

0 - Weight*	72.5 kg	
1 - Stature**	175.3 cm	
2 - Shoulder (acromial) Height	151.4 cm	59.6 in
3 - Vertex to Symphysion Length	87.5 cm	34.4 in
4 - Waist Height	104.8 cm	41.3 in
5 - Shoulder Breadth (Biacromial Breadth)	33.5 cm	13.2 in
6 - Chest Breadth	33.2 cm	13.1 in
7 - Waist Breadth	31.9 cm	12.6 in
8 - Hip Breadth	33.9 cm	13.3 in
9 - Shoulder to Elbow Length (Acromion-radiale Length)	999	999
10 - Forearm-hand Length (elbow-middle finger)	999	999
11 - Tibiale Height	999	999
12 - Ankle Height (outside) (lateral malleous)	999	999
13 - Foot Breadth	999	999
14 - Foot Length	999	999

Note: * weight in kilograms

** lengths in centimeters

*** measures 16 and 17 must be made in case where the subject will be used in the seated position during the tests. In all other cases enter 9999 when under these measures.

LABORATORY UMTRI D26 TEST NO. 83E131A-C

15 - Top of Head to Trochanterion Length		999	999
16 - Seated Height***		999	999
17 - Knee Height (seated)***		999	999
18 - Head Length		21.5 cm	8.5 in
19 - Head Breadth		15.4 cm	6.1 in
20 - Head to Chin Height (Vertex to Mentum)		25.9 cm	10.2 in
21 - Biceps Circumference		999	999
22 - Elbow Circumference		999	999
23 - Forearm Circumference		999	999
24 - Wrist Circumference		999	999
25 - Thigh Circumference		999	999
26 - Lower Thigh Circumference		999	999
27 - Knee Circumference		999	999
28 - Calf Circumference		999	999
29 - Ankle Circumference		999	999
30 - Neck Circumference		42.2 cm	16.6 in
31 - Scye (armpit-shoulder) Circumference		999	999
32 - Chest Circumference		99.8 cm	39.3 in
33 - Waist Circumference		999	999
34 - Buttock Circumference		999	999
35 - Chest Depth		23.5 cm	9.3 in
36 - Waist Depth		999	999
37 - Buttock Depth		999	999
38 - Interscye		999	999

LABORATORY UMTRI TEST NO. 83E131A-C

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