ATTACHMENT 4

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SUMMARY OF FUNDAMENTAL STUDIES ON METHODS FOR DETECTING, LOCATING, & CHARACTERIZING METALLIC LOOSE PARTS IN NUCLEAR REACTOR COOLANT SYSTEMS

PRESENTED AT THE NRC SURVEILLANCE & NOISE DIAGNOSTICS RESEARCH REVIEW MEETING IN BETHESDA, MD ON SEPTEMBER 22, 1980

- OUR WORK OBJECTIVE WAS TO -

BECOME SUFFICIENTLY ACQUAINTED WITH BOTH THE FUNDAMENTAL PHYSICS OF METAL-ON-METAL IMPACTS & THE LIMITATIONS IMPOSED BY PRACTICAL APPLICATION IN COMMERCIAL REACTOR LPMSs THAT WE COULD PROVIDE FACTS & IMFORMED OPINION TO NRC WITH REGARD TO TECHNICAL PERFORMANCE CHARACTERISTICS OF LPMSs, PRESENT & FUTURE.

- WE PURSUED THIS OBJECTIVE, BY MEANS OF -

- FUNDAMENTAL PHYSICS STUDIES IN IDEAL, 2-DIMENSIONAL, OPEN GEOMETRY (A SMALL FLAT PLATE)

- FOLLOW-UP STUDIES IN NON-IDEAL, 3-DIMENSIONAL, CLOSED GEOMETRY (THE EGCR VESSEL)

- THE MAJOR AREAS STUDIED WERE -

- INITIATION OF ACOUSTIC WAVES AT THE IMPACT SITE, INCLUDING PARAMETRIC DEPENDENCIES

- TRANSMISSION OF ACOUSTIC ENERGY THROUGHOUT GEOMETRICALLY COMPLEX, INHOMOGENEOUS STRUCTURES, INCLUDING DISPERSION & FREQUENCY-DEPENDENT ATTENUATION

- TRANSDUCTION OF ACOUSTIC ENERGY TO AN ELECTRICAL SIGNAL BY THE ACCELEROMETER, INCLUDING SENSOR MISMOUNTINGS LIKELY TO BE ENCOUNTERED

- SIGNAL PREPROCESSING TECHNIQUES FOR IMPROVING SIGNAL-TO-NOISE (S/N) RATIO

- SIGNAL PROCESSING TECHNIQUES FOR DERIVING ESTIMATES OF IMPACT LOCATION AND CHARACTER (SIZE, SHAPE, ENERGY OF IMPACTING OBJECT)

- DEGRADATION CAUSED BY BACKGROUND NOISE COMPARABLE IN LEVEL TO THE SIGNAL PRODUCED BY AN IMPACT

TIME DOES NOT PERMIT EXPLANATION OF THE RESULTS OBTAINED IN ALL THESE AREAS. HOWEVER, TWO NOVEL TECHNIQUES -- WHICH WE BELIEVE ARE CONTRIBUTIONS TO THE STATE OF THE TECHNOLOGY IN LPMSs -- DEVELOPED IN THE COURSE OF THIS WORK DESERVE MENTION:

1. USE OF THE TIME-DEPENDENT (I.E., SHORT-TERM AVERAGED) ROOT MEAN SQUARE AS AN INPUT SIGNAL TO BE PROCESSED, RATHER THAN THE RAW TIME-DOMAIN SIGNAL CUSTOMARILY EMPLOYED

   - AIDS IN INFORMATION EXTRACTION, SINCE BIPOLAR "RINGING" IMPULSE RESPONSE OF ACCELEROMETER IS ELIMINATED

   - NON-LINEAR TREATMENT OF LARGE SIGNAL MAGNITUDES ASSOCIATED WITH IMPACT IMPROVES S/N

2. DEMONSTRATION OF A LOCATIONAL ALGORITHM BASED ON SOUND ATTENUATION WITH DISTANCE, RATHER THAN ON RELATIVE TIMES OF SIGNAL ARRIVAL, AS IS CUSTOMARY

   - MUCH LESS SENSITIVE TO THE PRESENCE OF BACKGROUND NOISE

   - ADAPTS READILY TO VARIOUS COMMON VESSEL/PIPING GEOMETRIES

   - AUTOMATED MAXIMUM-SEEKING ALGORITHM DISPLAYS GOOD COVERGENCE PROPERTIES

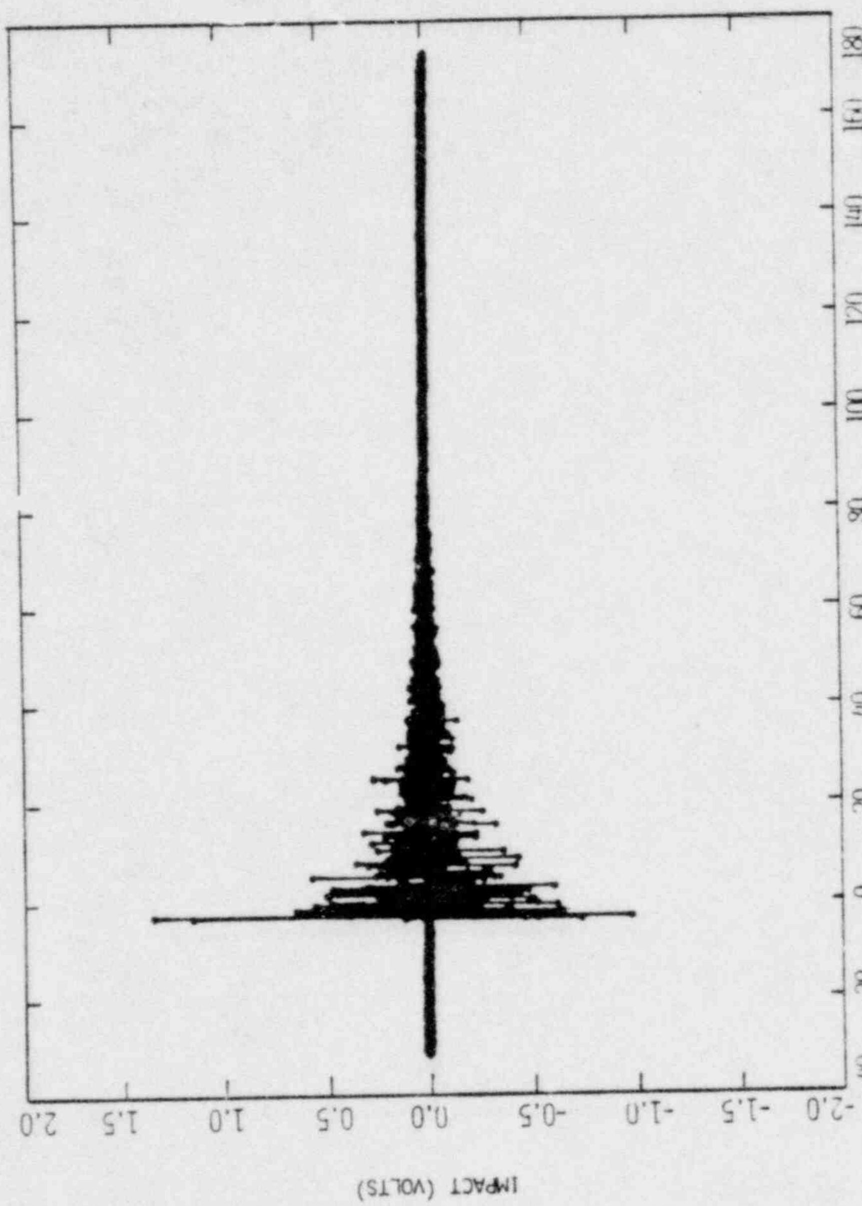


Fig. 46. A typical time domain impact signal.

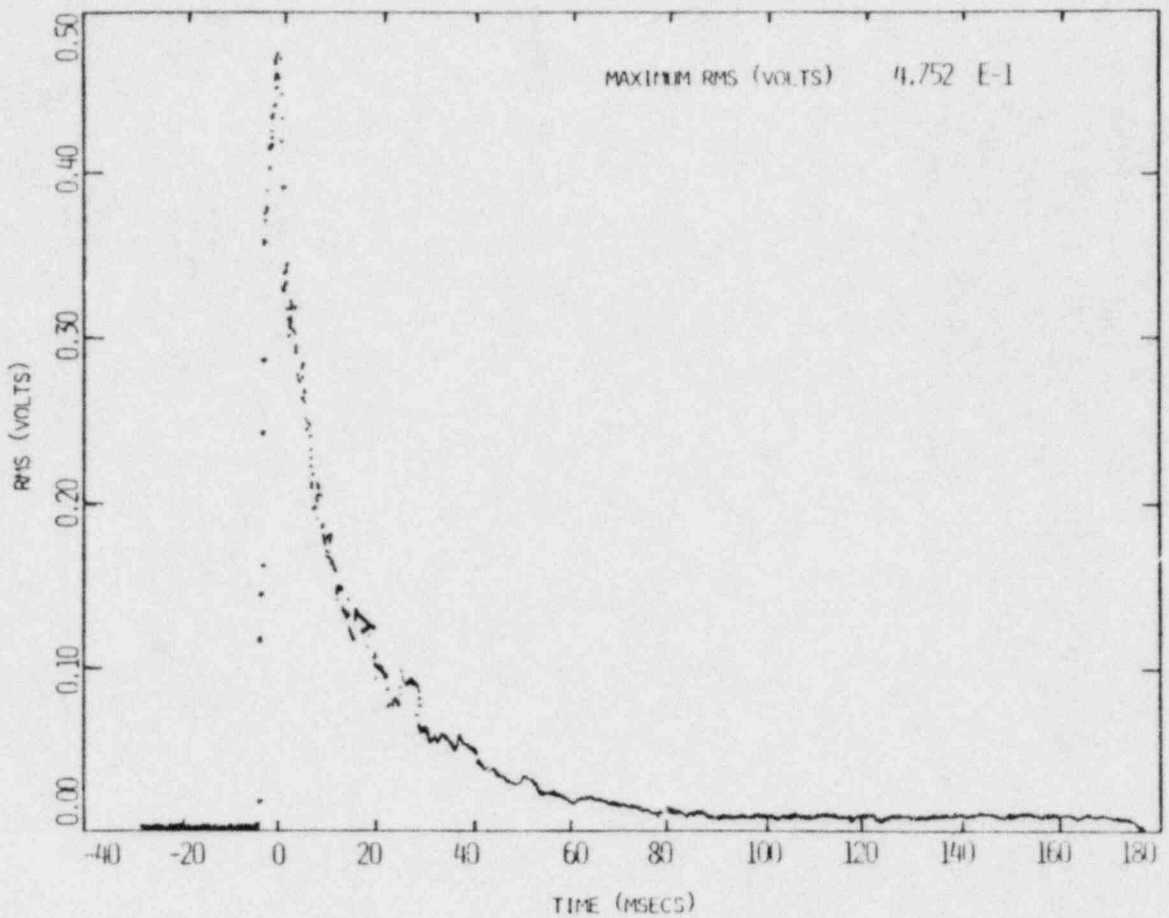


Fig. 47. A typical time dependent RMS of an impact signal.

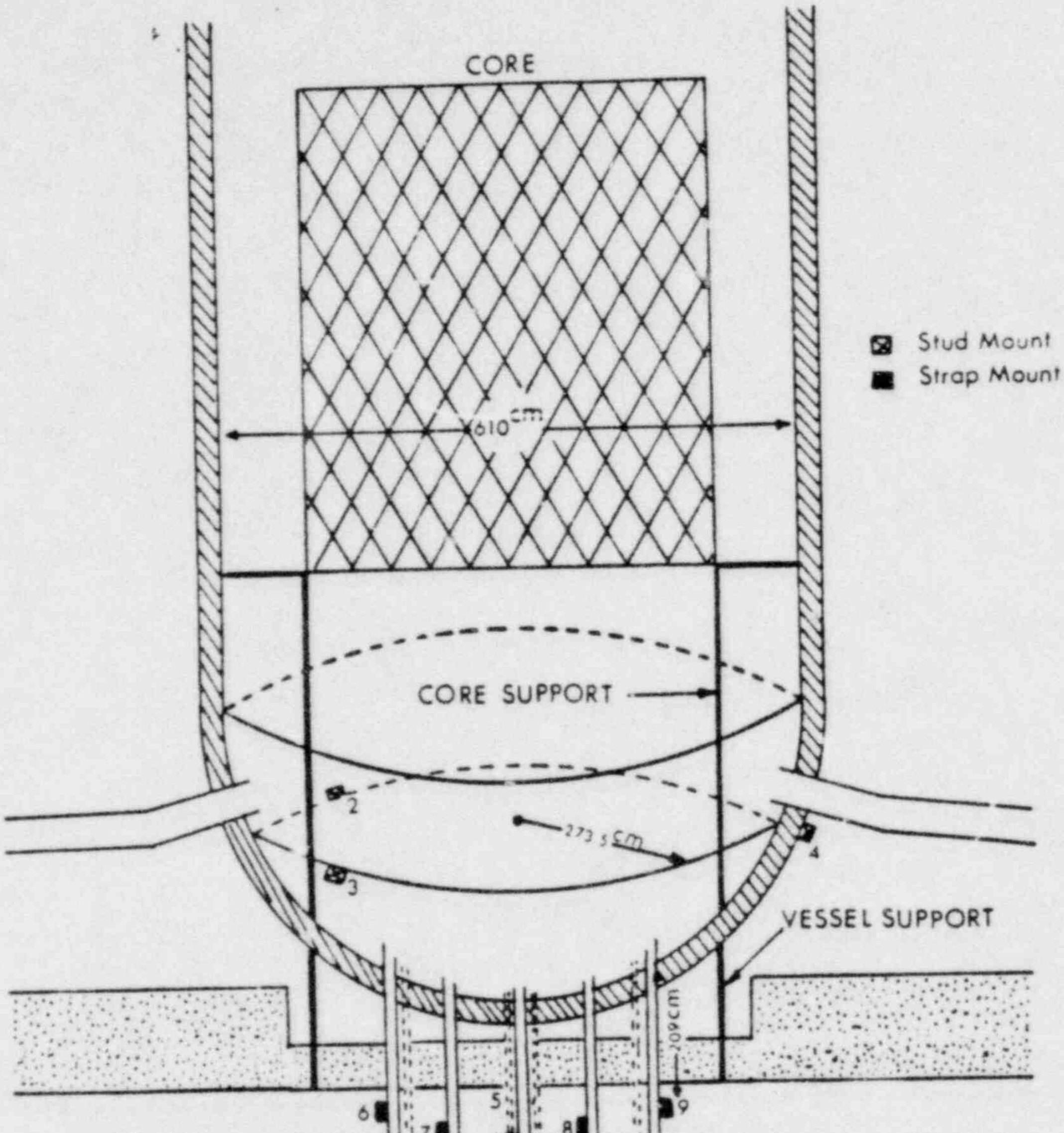
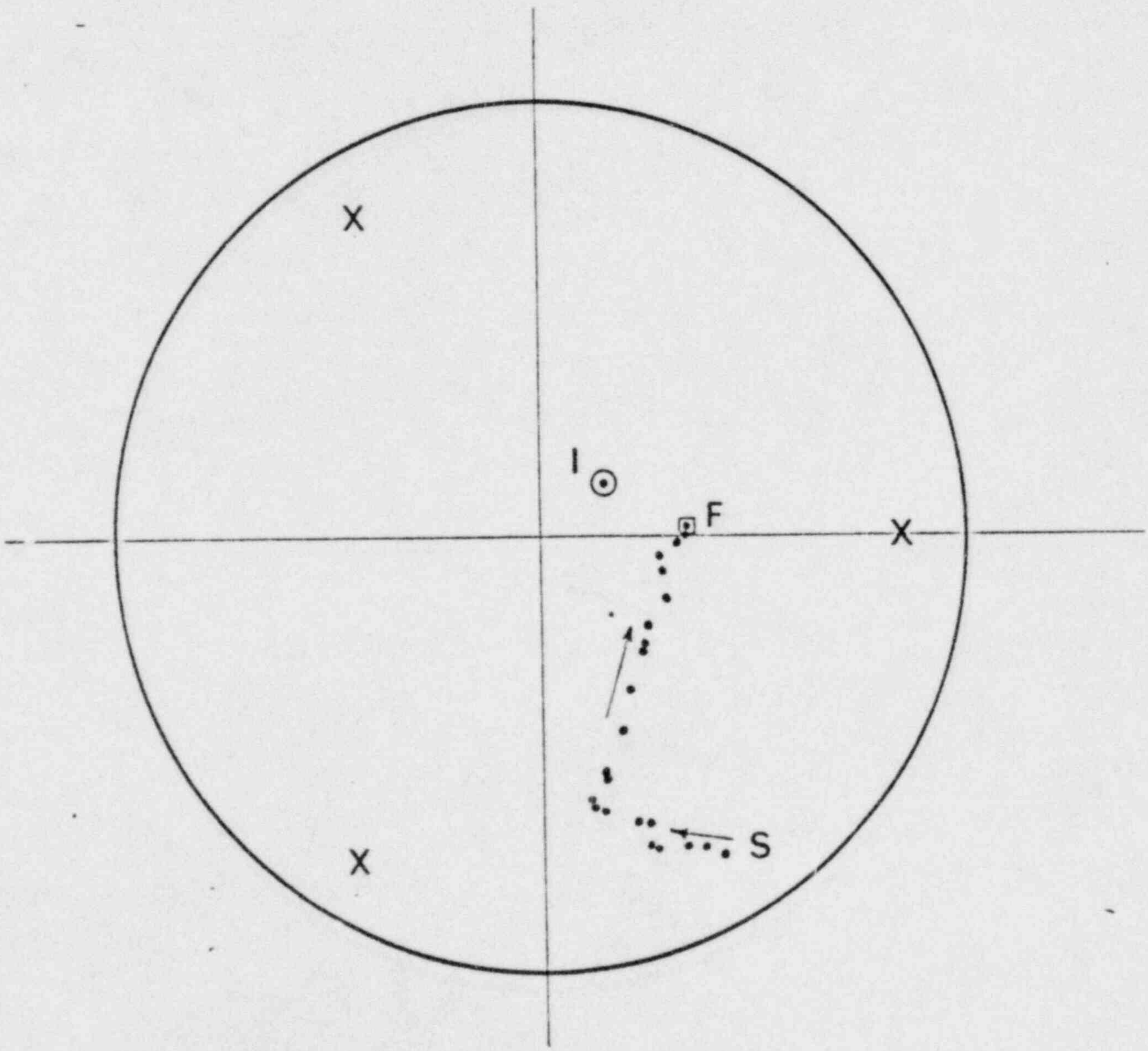
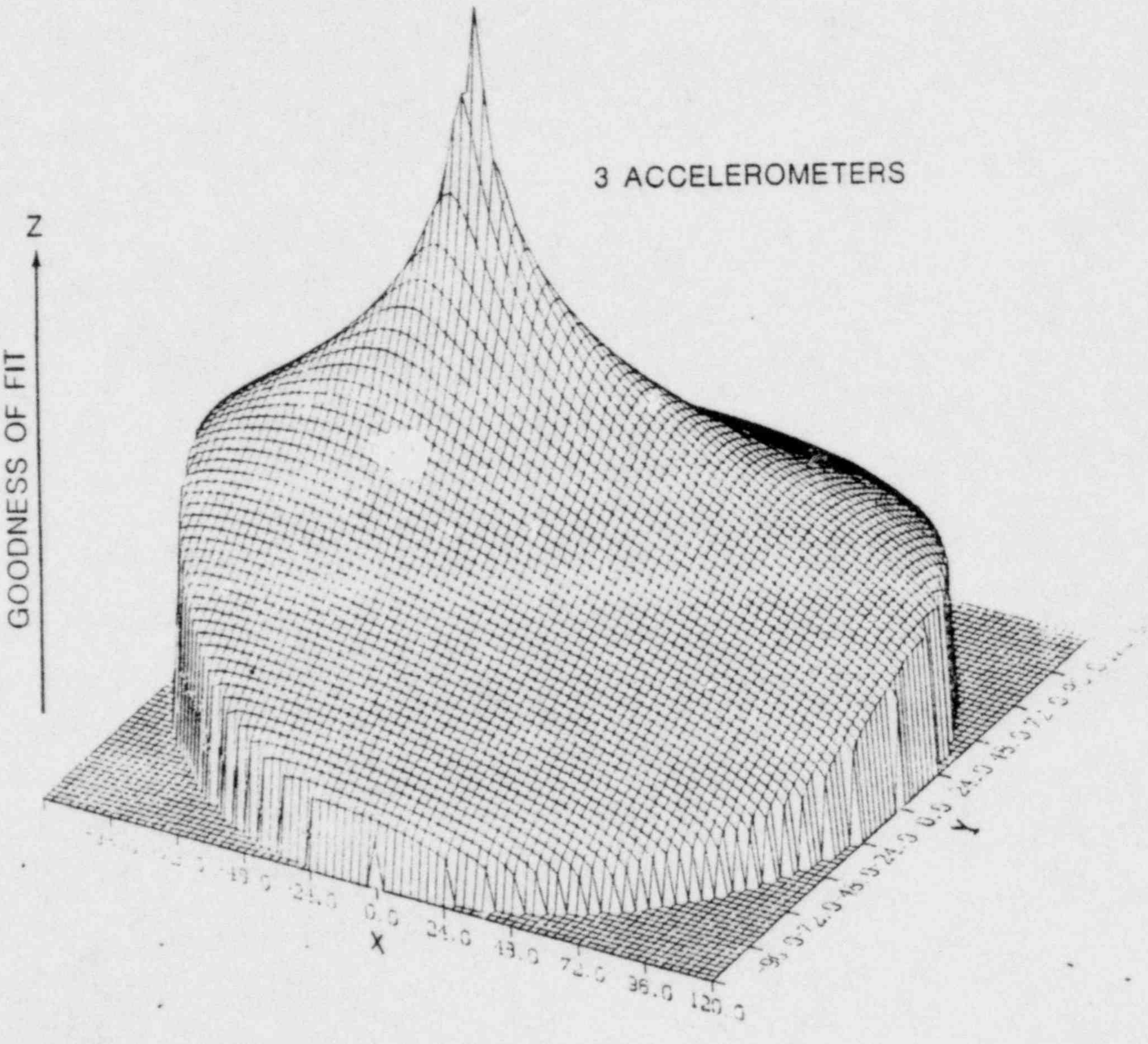


Fig. 41. Vertical view of the accelerometer locations 1 through 9 on the EGCR pressure vessel.

AN ITERATIVE SEARCH PROCEDURE, IN CONJUNCTION WITH A SUITABLE DESCRIPTION OF VESSEL GEOMETRY AND AN ASSUMED SOUND ATTENUATION LAW, CAN LOCATE THE IMPACT POSITION AUTOMATICALLY FROM THE ACCELEROMETER SIGNAL CHARACTERISTICS

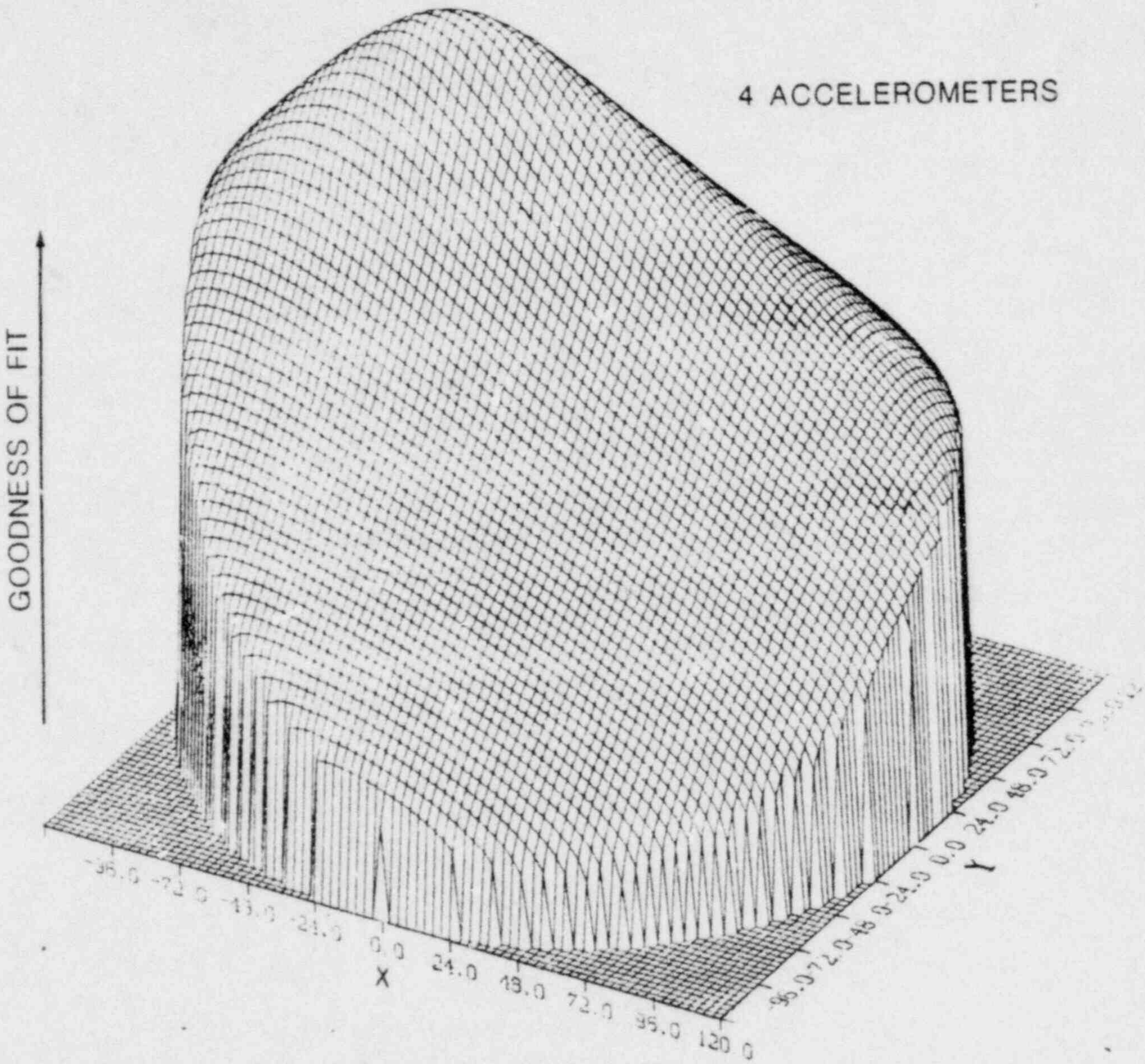


CONSISTENT, CRITICALLY-DETERMINED DATA SETS YIELD A WELL-DEFINED ESTIMATE OF IMPACT POSITION



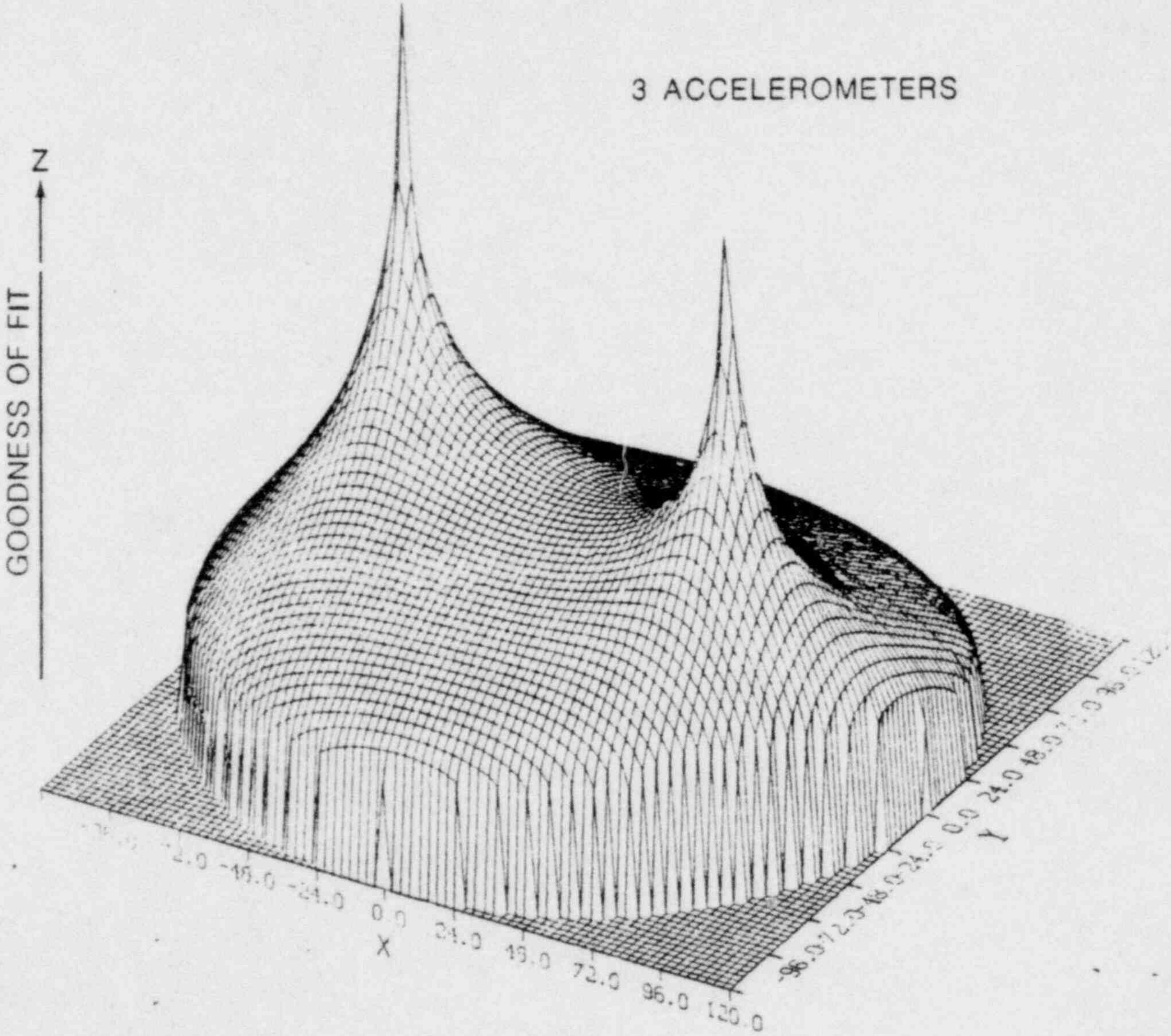
VESSEL COORDINATES

INCONSISTENT, OVER-DETERMINED DATA SETS YIELD A DIFFUSE ESTIMATE OF IMPACT POSITION



VESSEL COORDINATES

IF SENSORS ARE INSUFFICIENTLY SEPARATED, TWO POSSIBLE IMPACT POSITIONS OFTEN RESULT



VESSEL COORDINATES

GENERALIZING FROM THE ABUNDANCE OF DETAILED INFORMATION THAT WAS GENERATED IN OUR STUDIES, OUR MAJOR FINDINGS CAN BE CONDENSED INTO FOUR SIMPLE STATEMENTS (PLUS COROLLARIES & RECOMMENDATIONS):

1. IN CONTRAST TO SIMPLE DETECTION OF IMPACTS FROM METALLIC LOOSE PARTS, RELIABLE LOCATION AND CHARACTERIZATION ARE MUCH MORE DIFFICULT TO ACHIEVE

- WHY ? -

- REACTOR VESSEL & OTHER PRIMARY COOLANT SYSTEM STRUCTURES CANNOT BE TREATED ADEQUATELY AS IDEAL, HOMOGENEOUS BODIES
- CHARACTER OF SIGNAL RECEIVED AT SENSOR IS DETERMINED BOTH BY THE IMPACT'S CHARACTERISTICS (MAGNITUDE, SHAPE OF PROJECTILE...) & BY ITS DISTANCE FROM THE SENSOR
- EXCITATION OF MULTIPLE MODES OF SOUND WAVE PROPAGATION RESULTS IN NON-UNIQUE WAVE SPEED

2. BEST LOCATION/CHARACTERIZATION RESULTS ARE ACHIEVED WHEN SIGNALS ARE AVAILABLE FROM (A) MORE THAN ONE, (B) PROPERLY COUPLED SENSORS, (C) POSITIONED NEAR THE POINT OF IMPACT.

- S/N IS MAXIMIZED
- DISPERSION IS MINIMIZED
- REDUNDANCY COMPENSATES FOR INHOMOGENEITIES

- IMPLICATIONS ? -

- SPEND $ ON ADDITIONAL SENSORS, NOT ON MORE ELABORATE DATA PROCESSING
- UNREASONABLE TO EXPECT LOCATION/CHARACTERIZATION INFO FROM LPMS HAVING ONLY 6-10 SENSORS TOTAL

  (REG. GUIDE 1.133 PRESCRIBES MINIMAL LPMS)
  (UTILITY BUYING TREND IS TOWARD MINIMAL SYSTEM)

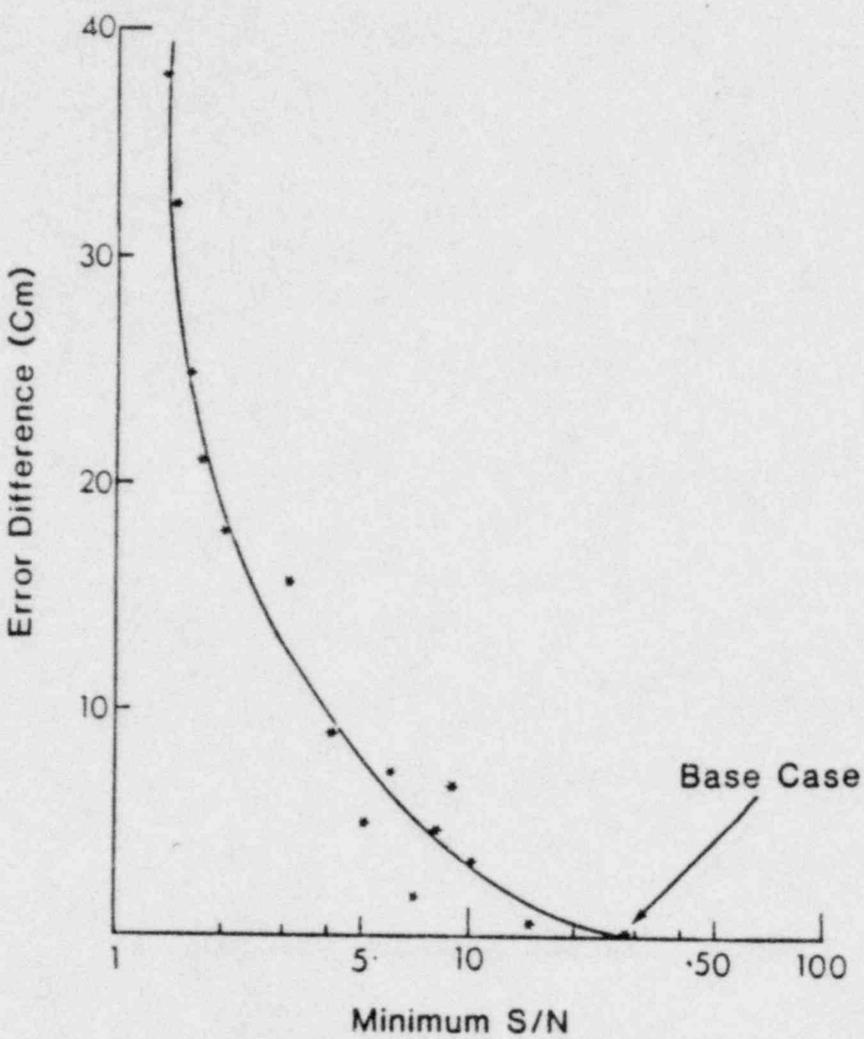


Fig. 49. Effect of minimum signal-to-noise ratio on the accuracy of impact location.

3. CHOOSING SENSOR LOCATIONS ON A BASIS OF EXPEDIENCY AND/OR ATTACHING THEM IMPROPERLY ARE SURE WAYS TO COMPROMISE LPMS PERFORMANCE.

- IMPLICATIONS ? -

- PROVISIONS FOR SENSOR MOUNTING & CABLE ROUTING SHOULD BE FACTORED INTO PLANT DESIGN AT AN EARLY STAGE

- "INDIRECT" ATTACHMENT SCHEMES (CRD's, INSTRU. GUIDE TUBES...) SHOULD BE AVOIDED, BECASUE THE SOUND TRANSMISSION PATH IS THEREBY COMPROMISED

- MAKESHIFT MOUNTING METHODS (MAGNETS, STRAPS, CLAMPS, ADHESIVES...) SHOULD BE AVOIDED

- PERFORMANCE CHECK OF COMPLETED SENSOR INSTALLATION IS EXTREMELY IMPORTANT; PROVISION FOR CALIBRATION DURING PLANT OPERATION (REMOTELY OPERABLE IMPACTOR) IS HIGHLY DESIRABLE

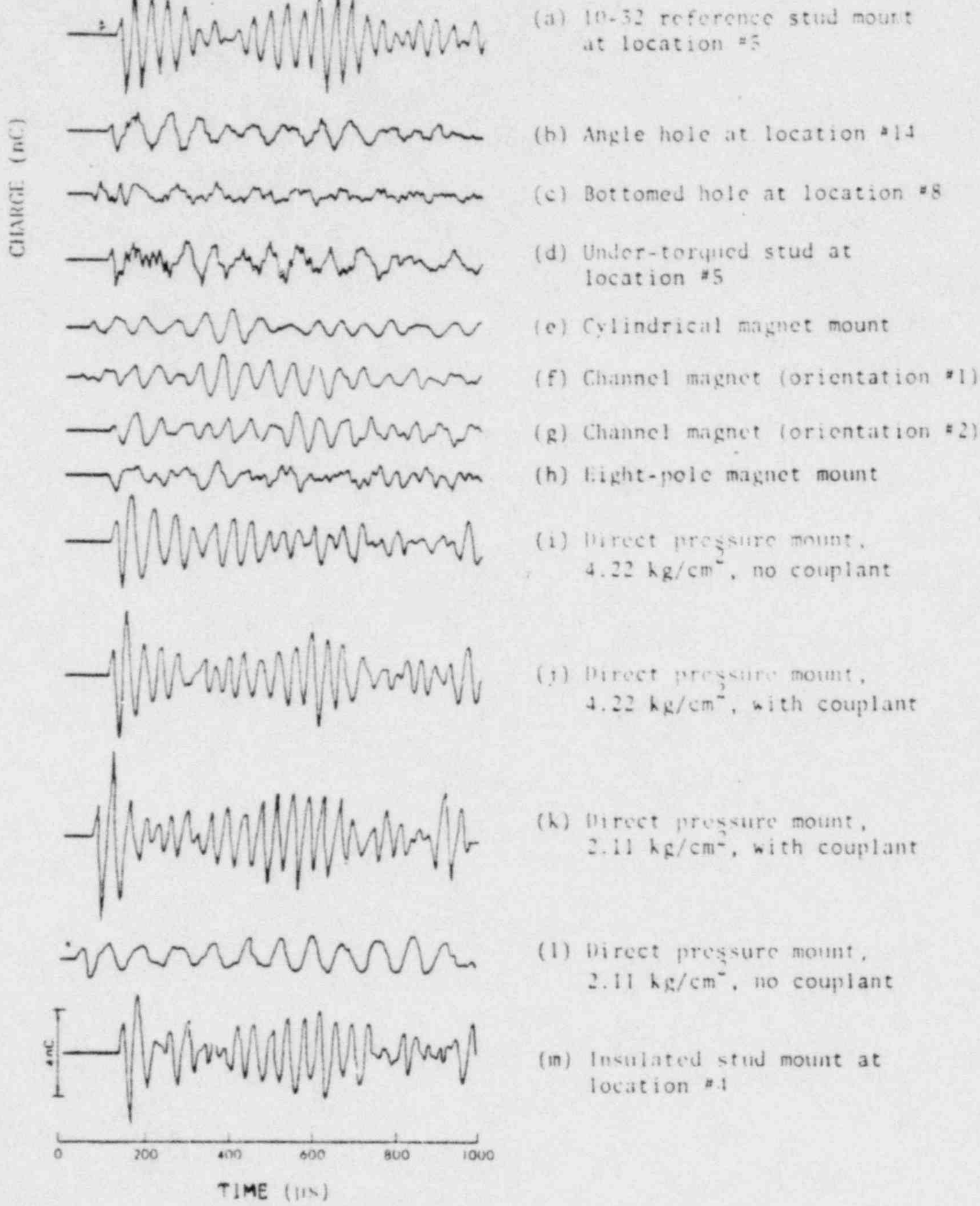


Fig. 12. Time-domain accelerometer responses to the impulse produced by a ball drop, for various accelerometer mounting methods. All traces have the same vertical and horizontal scales.

4. A THOROUGH SENSOR RESPONSE MAPPING, USING EITHER INTERNAL OR EXTERNAL IMPACTS OF VARIOUS MAGNITUDES & POSITIONS, IS THE FINAL ELEMENT IN ACHIEVING SUPERIOR LPMS PERFORMANCE.

- COMPENSATES FOR LOCAL SOUND PATH PERTURBATIONS AND OTHER NON-IDEALITIES
- ALLOWS CHARACTERIZATION TO BE SEPARATED FROM LOCATION
- QUALITY ASSURES & CALIBRATES ENTIRE LPMS

- IN SUMMARY -

- CARE IN DESIGNING, INSTALLING, CALIBRATING, AND TESTING A LPMS IS REQUIRED IF A MAXIMUM AMOUNT OF INTERPRETABLE INFORMATION IS TO BE DERIVED FROM IT

- AS A RESULT OF OUR GROUNDWORK STUDIES OF ACOUSTIC PHENOMENA BASIC TO LPMSs (IMPACTS, SENSOR MOUNTING METHODS, SOUND TRANSMISSION IN COMPLEX STRUCTURES, METHODS FOR ESTIMATING SIZE & POSITION OF IMPACTING OBJECT ...) WE HAVE ACQUIRED KNOWLEDGE THAT WILL HELP US TO BE MORE EFFECTIVE CONSULTANTS TO NRC ON REGULATORY QUESTIONS INVOLVING LPMSs