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In Vivo Detection, Localization, and Measurement of
Radionuclides in Man: A Detection System for the
Localization and Measurement of Small Amounts of
Photon Emitters

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Abstract

The objectives of this research involve the design, development, and testing of a new type of photon detection system which can provide, simultaneously, magnitude and positional data regarding a radioactive source, without utilizing a high-Z collimator. This system employs the principle of active collimation, i.e., the geometric configuration of crystal elements results in certain members being shielded from oblique-angle rays, thereby providing spatial resolution characteristics. Inasmuch as events occurring in the promontory shielding crystals can be used to determine activity levels of the emitter, a greater counting efficiency is attainable than that with other currently available systems. Owing to optical and scintillation characteristics, and amplifier parameters, along with masking of the common PM tube, each of the five scintillation crystals in the detector configuration produces a separate, delineable spectral peak.

Multiple product terms developed from the background-corrected counts of the recessed NaI(Tl) peaks represent an extremely sensitive indicator of detector position with respect to source, while the promontory CsI(Na) crystals provide simultaneous quantitative activity level information.

By incorporating detectors in an array or mosaic, additional spatial resolution information should be derived, at the same time reducing the degree of detector movement required to obtain a given response. Rather than invoke the expense

of physically constructing such a multidetector configuration for testing and evaluation, it was decided to simulate performance by computer program, based on actual response of the detector as obtained by experiment.

Extensive detector response data were obtained using a converted Nuclear Chicago Pho-Dot scanner as an automatic positioning device for the detector, operating in conjunction with a specially-developed position control unit (PCU) and a spectrum analyzer equipped with a dedicated computer. Under automatic program control, the detector scanned, in 5 mm steps, a 144 cm² field about a ¹⁰⁹Cd point source. The coordinates of each measurement location were indicated along with printout of background-corrected peak counts, multiple product terms, and propagation of error data.

The various corrected peak counts were then utilized to derive quadratic curve-fit functions to approximate individual crystal responses. These were included in a synthesis program designed to simulate the overall response of a 3 x 3, nine-detector array, configured such that the crystal alignment of each detector was rotated 90° with respect to that of its neighbors, thereby resulting in a parquet pattern.

The program produced multiproduct terms of the nine-detector array as a function of abscissa displacement as the detector scanned a variety of different "source" shapes, such as a single point, line segments of various inclinations, and circular configurations. Subsequent analysis of these results enabled the formulation of certain conclusions as to

detector characteristics, and suggested likely approaches for the utilization of the device in an advanced imaging system. Salient points are the following:

1) The array is extraordinarily responsive to small positional changes, e.g., when a 5 cm line segment is scanned, product output of the approaching detector suddenly increases from background to an 8th order of magnitude value within a distance of only 2 mm. The actual response interval is doubtless even smaller, but its precise determination must await a more refined simulation analysis. This sudden but enormous change in the multiproduct output is a result of a "switch on" effect that occurs when a recessed NaI(Tl) wafer, on the side of the detector distal to the source, arrives at a position where it can be just barely illuminated by source photons. Only a miniscule movement of the detector is needed to bring this side NaI(Tl) crystal into a geometric relationship with the most proximal point of the source such that obtuse-angle illuminating photons can glance past the knife edge of the adjacent promontory CsI(Na) crystal.

2) There is an exact and consistent relationship between the location of the edge of a source, regardless of its shape, and that detector position where a sudden change in the multiproduct factor takes place. This location also coincides with the point of maximum slope change in the multiproduct factor, thereby indicating that it would be possible to utilize the relative change in output, rather than absolute count data for position determination and imaging. Thus, detector per-

formance may be made essentially independent of background and count rate.

A further series of experiments will commence shortly to evaluate performance of another promising version of the active collimation detector which, however, utilizes a 3×3 array of individual circular NaI(Tl) detectors, 1.27 cm in diameter $\times$ 1.9 cm long, each with photomultiplier tube. This approach provides completely separate spectral peaks, and the system will again be explored using a computer synthesis method analogous to that already described. Once the characteristics for a multi-group array have been determined, a comparison study will be undertaken and a selection of the optimal design will take place. Then, data reduction techniques will be developed in order to translate detector response into precise source position information for localization or imaging purposes.

Significance

There is great potential importance for a system capable of defining, quickly and accurately, the location and magnitude of low level radiation sources. An obvious application would be in instances of accident where radionuclides enter the body, and it becomes of immediate importance to ascertain both the sites of deposition and their activity levels for dosimetric calculations.

In addition, there appear to be very substantial applications in the field of nuclear medicine because of the improved resolution-to-activity factor foreseen for the system. Good imaging should be obtainable with much lower radiation exposure levels than is possible with present models.

Still another area of significant potential would involve the surveillance and monitoring of radioactive plumes or clouds in the atmosphere. It is envisioned that arrays comprised of scaled-up versions of the present detector, deployed geographically in appropriate triangulation configurations, would provide information regarding the shape and location, as well as drift pattern and velocity, of radionuclide emissions being borne in the atmosphere. In the event of a nuclear accident or act of war, this type of data could be of extreme importance for organizing civilian protection or in directing the evacuation of a population.

In view of the interest accorded extragalactic X-ray emanation sources, it would appear that a macrosized version of this system also holds promise for such astronomy investigations. Suitably located arrays should be able to provide more precise information as to the size and location of these outer space sources.

Operational Details

The Mod II prototype detector uses a series of interleaved NaI(Tl) and CsI(Tl) crystals, each 7.6 cm thick, whose position and general configuration result in active collimation, as will be explained.

Three NaI(Tl) elements, located at the detector center and sides, are recessed 19 mm behind the CsI sections (Fig. 1), thus preventing their illumination except by photons whose angle of incidence is almost normal to the wafer surfaces. A common PM tube is suitably masked and positioned with respect to the five-crystal assembly so that it is illuminated non-uniformly, thereby permitting separated spectra to be obtained from each crystal (Fig. 2). This multipeak output results from the internal reflective coatings between wafers, their individual light decay characteristics, efficiencies, emission spectra, relative position with respect to the PM tube, and degree of masking.

Initial evaluation of the Mod II detector was interrupted by a manufacturing defect; securing the detector with reasonable restraint in its mounting resulted in rupture of the hermetic seals, causing hydration of the NaI(Tl) wafers. This problem was initially observed as a progressive shift of the NaI(Tl) spectra towards lower energy regions. At first, the full significance of this was not appreciated and it was thought that the masking was shifting. Upon disassembly of the unit, the characteristic yellow color of the hydrated elements was noted.

Unfortunately, rectification of the problem by the manufacturer proved to be extremely time-consuming. The housing had to be redesigned to take cinching strain off of the seals. New stainless steel enclosures had to be engineered and a number of months passed before the replacement unit was received.

Awaiting return of the Mod II detector, the performance of thin NaI(Tl) crystals having various widths (6.5 mm, 4.5 mm, 2.5 mm) was evaluated. The purpose of this study was to ascertain whether a thinner scintillator section was feasible as this would reduce the range of incidence angle that could be viewed by an element and thereby improve detector spatial resolution. Offsetting this benefit, however, would be deteriorating intrinsic resolution resulting in one crystal's response overlapping those of its neighbors in a manner that precluded data separation with the use of a common PM tube.

Each NaI(Tl) crystal was evaluated by illumination with a 250 μ Ci ^{109}Cd source, positioned behind a 1 cm x 4 x 2 block of bismuth, through which a 1.5 mm diameter collimation aperture had been bored. Detectors incorporated demountable-type scintillator assemblies, so that the associated RCA 4855 photomultiplier tube could be removed or interchanged for inspection or comparison purposes.

When the source was placed at midpoint of the detector end, midheight, the amplifier gain was adjusted to put the center of the peak in channel 297. The collimated source was then repositioned so that it illuminated the detector side at

a point 5 mm in from the end corner. It was assumed that this point was displaced far enough from the end to assure impingement of photons on the crystal itself, rather than intercepting a portion of the support within the detector housing. Then, the source was repositioned at approximately 5 mm intervals along the side, virtually up to the PM tube abutment with the scintillator. At each location center channel counts, along with full-width, half-maximum values vs. channel, were taken for the ^{109}mAg gamma ray, as well as for the 22 keV X-ray. This process was repeated for each crystal, with amplifier gain being adjusted in each case to establish the peak energy at the same center channel location to allow direct comparison.

Tests of a 4.5 mm wide NaI(Tl) crystal were undertaken first. The energy of the spectrum centers obtained when a collimated source illuminated identical sectors of the end and sides did not correspond within reasonable measurement error bounds and necessitated investigation to determine the reason for the shift. Moreover, difference in spectra appearance was noted.

At first it was believed that a boundary effect might be involved that permitted a significant number of events to escape undetected near the crystal edge. Removing the Cu shield from the collimator demonstrated that even the 22 keV ^{109}mAg X-ray was experiencing a significant shift. Calculation showed that 99% of all 22 keV interactions would be absorbed in 1 mm thickness, so another explanation was sought. After ruling out voltage variation and equipment or cable

problems, attention was directed to the fact that areas of different magnitude were involved, depending upon whether the side or end was illuminated. This suggested the possibility that backscatter was involved, since there was significant probability of Compton events at 88 keV. This was confirmed when the spectral differences and shift were essentially eliminated by shielding the exposed portion of the source behind the collimator. FWHM resolution of the 4.5 mm wafer, illuminated at the end, was 19% and remained essentially constant along the edge up to 30 mm from the front. The 6.5 mm wafer had slightly better resolution, starting at 18%, also remaining essentially constant with illumination at various points along the edge. A 5.5 mm wafer section developed the same hydration problem as the Mod II detector assembly, although the design of its hermetically-sealed enclosure was entirely different. It was not returned from the factory until a relatively advanced date, precluding its inclusion in Table I, although its values are expected to be between the 4.5 and 6.5 mm elements.

In the conventional analysis of scintillator performance at these energies (^{109}Cd γ = 88 keV) intrinsic resolution is considered to be dominated by statistical variation stemming from the available number of information carriers. Thus, such an analysis would suggest that this parameter, per gamma, for a scintillator would be, assuming 13% scintillator efficiency, 33% light loss at crystal surface, and 20% photocathode efficiency,

$$\text{No. PM information carriers} = \frac{88 \times 10^3 \times .13 \times .66 \times .20}{4 \text{ eV}^*} = 377$$

Therefore, theoretically, for every photon impinging on the detector, only about 2900 light photons result and, of these, only 13% or approximately 380 primary electrons are available for cascade amplification.

However, data from the thin crystal sections indicates that variation in light collection efficiency with thickness, i.e., changes in scintillator optical properties for different widths, appear to be the dominant factor where narrow dimension sections are involved. After an initial negative shift, a progressive forward shift of peak center channel is observed as point of illumination is advanced from approximately 17 mm beyond the front edge and proceeds towards the photomultiplier interface (Fig. 3). The greatest number of photons reach the photomultiplier when the interaction occurs at 30 mm from the end, or in close proximity to the photomultiplier interface than is the case when interaction occurs at a point more remote from the photomultiplier. Light photons appear to be lost in the latter instance, thereby shifting the peak to the left or into a lower energy domain. As will be noted, a 24-channel shift occurred with the 4.5 mm crystal, while a 14-channel change was observed with the 6.5 mm crystal. Percentage-wise, these changes are too small to exert measurable effect on the

* Radiation Detection and Measurement, G. F. Knoll, John Wiley and Sons, N.Y., 1979.

calculated intrinsic efficiency, although they nonetheless demonstrate a variation in detector photon flux with site of interaction. Also, the 24-channel shift with the 4.5 mm crystal suggests that the scintillator's response to uncollimated point source illumination from the side would result in a broadened peak having deteriorated resolution.

In view of the 15% FWHM obtained with the 7.6 mm-thick crystals in the Mod II, it would appear that this dimension is approximately optimum. Below this, intrinsic resolution worsens.

Upon return of the Mod II detector, it was discovered that, owing to a change in manufacturing technique, the ability to separate the two CsI(Tl) peaks was now somewhat compromised. Inasmuch as the multiproduct terms used for detector spatial resolution involved only the NaI(Tl) crystals, which were not affected, partial superimposition of the CsI peaks was not of any consequence in evaluating the resolution capabilities of the detector.

The combined counts in the CsI crystals 2 and 4 was therefore identified as Region I; NaI crystals 1, 3 and 5 becoming Regions 3, 5, and 4 respectively.

A program was written in Interactive Basic, the language of the dedicated Nova 2 computer incorporated in the Tracor-Northern TN-1700 Pulse Height Analyzer, to automatically derive the peak counts, subtract background, including interferences between peaks, and develop the multiproduct terms as a function of detector position with respect to a source.

Guard bands approximately 21 channels wide were established in the troughs between peak Regions 1, 3, 4 and 5. The sum of counts in a pair of guard bands bracketing a given peak divided by the sum of their widths gave the average background count value per channel, so that multiplying this value by the peak region width yielded the total region background to be subtracted from the gross region counts.

Owing to differences in the areas encompassed under region peaks as a function of energy, there would be a different number of counts in Regions 3 and 5 when detector centered over a source if the entire peak spectra were incorporated. The size of Region 4 was adjusted therefore so that the net Region 4 counts matched the net value derived from Region 3 when the detector was centered with respect to a point source.

Response of the Mod II prototype detector at various locations about a point source was obtained by securing the detector in a shielded enclosure and mounting the assembly in the moving arm of a Nuclear-Chicago Pho-Dot scanner which was converted to operate as an incremental scanning device. The Nova 2 computer was modified so that it provided an actuation trigger, under control of a stored sequence, to a position control unit which produced successive 5 mm incremental movements of the detector arm. The position control unit (PCU) was designed and built in this laboratory to complete the logical loop between the Nova 2 and the converted Pho-Dot scanner. Following each repositioning of the Pho-Dot moving arm and its detector, the PCU indicated the new location of the detector

center by a mark struck electronically on a sheet of graph paper that was precisely oriented on the Pho-Dot table. The exact location of the source was indicated on the sheet by having previously positioned the detector over the source, using a centering device, and striking a mark to delineate the source center. Determining the coordinates of each position of the detector was therefore a simple matter of merely reading these values from the graph paper grid. The source, mounted in a cross-hair cursor, was emplaced on a similar sheet of graph paper affixed to a laboratory bench. The Pho-Dot arm was free from play and flexure, thereby assuring integrity of the measurements.

When the location was marked, the PCU transmitted a start pulse to the Nova 2 computer enabling the commencement of a 300-second count. The stored program then provided on-line typeout consisting of station number, individual region counts corrected for background (using guardbands as previously described), and the multiple products resulting from left and right side crystal counts. The propagated error was also provided for each output, starting with gross counts and error in the guardbands.

Upon completion of typeout for a given detector position, a trigger was sent to the PCU to initiate movement of the Pho-Dot moving arm to a new position and the process repeated itself.

Data was taken in a field to the left of the source, or in the second quadrant if the source is presumed as being at

the origin of the coordinate system. This was ordained by clearance considerations affecting the travel of the detector arm. The dimensions of the field were dictated by the need to cover an area equal to that of 3 x 3 detector array (Fig. 5) or approximately 114 mm square. A somewhat larger area was actually covered when it was discovered that the variation of counts in the downfield or Y_i^* direction followed an extremely gradual function, and therefore a somewhat longer ordinate distance was covered. At the end of a preset abscissa distance, governed by adjustable limit microswitches, the Pho-Dot scanning mechanism moved downfield incrementing approximately 5 mm along the ordinate, and began a return track to the opposite abscissa limit, whereupon the arm actuated another microswitch and the arm again stepped 5 mm downfield and traveled along the abscissa on a reverse track.

This automatic capability enabled a large number of small incremental values to be obtained without manual intervention over counting intervals sufficiently long as to provide the desired level of statistical significance. Paper tape punch-out of data was also produced in the event that further analysis of information by a computer should prove desirable.

Unfortunately, frequent and unpredictable power outages and voltage transient perturbations caused dropout of the Nova 2 computer and necessitated reloading the system. This

* Y_i is used to delineate the ordinate value of the detector, as opposed to Y values derived from linear regression and quadratic curve fit equations, which are really regional counts.

process was extremely cumbersome and time-consuming with the present computer configuration, limited as it is to punch-tape input, and due to the volume of tape to be entered, the operation can take a day. Transients occasionally also resulted in PCU malfunction. These recurring problems seriously impeded progress.*

Although detector responses to a point source were taken essentially for the second quadrant, as described, four longer scans were made from approximately -115 to +100 mm along the abscissa, covering an ordinate range from $Y = 0$ to $Y = 16.5$ mm. When these detector responses were plotted as a function of detector X and Y displacement from the source, it was found that the plots obtained were essentially identical for this range of Y_i . As will be described, the longitudinal function was subsequently noted to be very slowly varying when compared with the transverse (abscissa) function. This can be understood in terms of the geometry of the detector, as along the longitudinal axis there is no crystal shielding until the edge of the detector housing begins to obscure the illuminated cross section, which decreases with increasing parallax effects.

Looking at the function plots of region response vs. detector displacement (Fig. 4), it can be seen that as the detector passes over a point source, the output of any given crystal follows a ramp function until that element is exposed to unobstructed illumination where the output becomes essentially constant. As the detector continues its course, another

* Plans are presently under consideration for an interruption-free, battery-based power system, similar to the type used by telephone utilities.

ramp function of opposite slope is obtained. Thus, the plateau region occurs when that crystal is approximately over the source and neither the adjacent CsI wafer(s), nor the housing in the case of end wafers, is interposed into the illumination path. If the detector is rotated 90° , very similar wafer response behavior should be exhibited, but the nominal length of the plateau would then be related to the much longer longitudinal dimensions; 38.1 mm vs. 7.6 mm for case that is plotted. As the detector moves in the downfield or increasing ordinate direction, a function is obtained that is analogous to the X-function plot, but has a different ramp slope, deriving from obscuration by the lead-cadmium-copper laminated shield which skirts the detector.

When the response data was plotted as a function of X, the net displacement of the detector from the source for a series of 2.5 cm increments in the Y_i direction, a family of response curves was obtained for the Y_i values, each plot showing a slowly decreasing ramp slope. It was found that the Y_i function could then be approximated linearly and incorporated in a linear regression routine just as the X function.

Linear regression functions were thus derived for the responses of the three regions, R_3 , R_4 , R_5 , for use in the response-approximation expressions of the synthesis program.

However, the nonlinear relationship existing between portions of the ramp equations for R_3 , R_4 and R_5 and Y_i , the downfield displacement of the detector, could not be ignored in synthesizing the detector response. Further investi-

gation of the variations of slope coefficient as a function of Y_i suggested that a curvilinear fit of the expression should be possible. Subsequently, it was found that the relationship for each region could be closely approximated by an individual quadratic equation. The method of divided differences was used to fit quadratic equations through points $Y_i = 0, 22, \text{ and } 50.5 \text{ mm}$ at one boundary of the expression, and $Y_i = 50.5, 79, \text{ and } 115.5 \text{ mm}$ for the downfield portion of the expression. This quadratic equation curve-fit technique was employed to derive the slope coefficients of each region's ramp functions, as well as the intercept term of the particular regression equation.

To demonstrate this methodology, it will be noted that the adjusted slope coefficients* of $R_{3\text{Low}}$ vary from 3.2 at $Y_i = 0$ down to 0.49 at $Y_i = 115.5$ (Refer to Table I). The corresponding values of the adjusted regression intercept terms range from 100.4 for $Y_i = 0$ to 16 at a downfield displacement (Y_i) of 115.5. The quadratic approximation of the $R_{3\text{Low}}$ slope coefficients is expressed as follows:

$$\text{Slope Coefficient } M_{31}^{**} = -.00051 Y_i^2 + .0022 Y_i + 3.2$$

This expression applies between $Y_i = 0$ and $Y_i = 50.5$.

* Adjusted coefficients were obtained by averaging the slopes of the R_3 and R_4 ramp functions to account for slight differences in slope, depending on whether the crystal is being shielded by the CsI promontory crystal or the Cu-edge.

** Notation throughout the program utilized two subscript modifiers of M and I, the first denoting region number, followed by 1 (for Low) or 2 (for High).

For the region between $Y_i = 50.5$ and $Y_i = 115.5$, the slope coefficient was determined by the expression

$$M_{31} = .00227 (Y_i - 50.5)^2 - .0381(Y_i - 50.5) + 2$$

When Y_i values in the ranges indicated are entered into the appropriate equations, the resulting M_{31} value becomes the coefficient of a linear regression

$$Y = MX + b$$

The "b" value or intercept terms were derived in analogous fashion. For the range $Y_i = 0$ through $Y_i = 50.5$, this term is represented by the expression

$$INT_{31} = -.0136Y_i + .0777Y_i + 100.4$$

Similarly, for the Y_i range 50.5 through 115.5, the intercept term is approximated by

$$INT_{31} = .00533(Y_i - 50.5)^2 - 1.17(Y_i - 50.5) + 69.5$$

By utilizing nests of these stored expressions in the synthesis program, the response of each crystal can be directly computed, based on the X and Y_i coordinates of the detector center. The values obtained corresponded quite closely to the measured regional net counts.

It was not necessary to use a curvilinear approximation for the plateau or peak responses of R_3 , R_4 and R_5 , which could be accurately represented by ordinary linear regression equations.

With the detector response thus totally defined, a set of specifications for the detector synthesis program could then be set forth, in terms of the variables that were to be explored.

The Mod II system consists of an array of detectors in a 3 x 3 matrix configuration, wherein the center unit has its crystals aligned vertically, every adjacent detector being rotated 90° with respect to the crystal alignment of its neighbors so that a "parquet" crystal pattern results (Fig. 5). The program then must develop, as needed, the region responses for both vertically and horizontally-aligned wafers. Provision was also made for the center detector crystals to be horizontally aligned, thus reversing the "parquet" pattern. This alignment reversal permits a horizontal scan to simulate vertical (Y_i) incremental sweep, as will be subsequently explained.

In addition, the program was written to allow the 3 x 3 detector array center to be located at any desired set of coordinates in the 133 cm-square field and successively view one or more point sources located in the coordinate system. For each position of the array, the respective regional counts for each detector, in turn, are both indicated separately and as a running cumulative total for each point source that is viewed. In this manner, the response of a single detector to any simple or complex source configuration may be ascertained by an iterative step-by-step integration process.

An implicit requirement was that the program must have capability of analyzing the position of a given detector anywhere in the field with reference to the coordinates of a specific point source. The computer routine must have the logic to interpret whether a detector center is to the left

or right of the source in question, and whether it is upfield or downfield.- or ascertain whether the respective coordinates coincide. In addition to spatial recognition, the program must perform coordinate transformations and algebraic geometry arithmetic to provide net difference in X and Y values for the detector with respect to any point source. When the detector's X coordinate is more negative than that of the source, crystal 1 receives more illumination than crystal 5, so the number of counts in Region 4 must be correspondingly greater than those in Region 3 for this condition. For emanation from a point source whose X coordinate is more negative than that of the detector, the reverse would be true.

Similarly, if the detector was positioned such that its net X value were zero, although displaced in the Y_i direction, values of R_3 and R_4 must be equal.

Because the array geometry can be confusing, the synthesis program was written so that the printout for each detector includes its coordinates for that position of the array and the coordinates of the source being viewed in that particular iteration.

When the last point source has been viewed by a detector, the multiproduct terms were printed out for the accumulated region responses as $(R_{3T} \times R_{4T}) (R_{3T} \times R_{5T}) (R_{4T} \times R_{5T})$, etc. and the next detector in the array was similarly synthesized (Fig. 6). Upon completion of this processes with the last detector (3,3), and printout of its multiproduct terms, the program "repositions" the detector array by a prescribed

increment (which was entered at the start of the program) along the abscissa, and the iterative process repeats itself for the entire array.

In this manner, the response of a vertically scanning detector array can be synthesized for any source configuration. To simulate vertical movement along the ordinate axis, the scanning process is still performed along the abscissa, but at the start of the program, the center detector is set forth as having horizontal crystal alignment rather than the initial vertical alignment. Since this reverses the parquet pattern as previously described, the result is a coordinate axis transformation such that the same X-scan motion now synthesizes Y_i axis movement.

Conceptually, the program logic proceeds by first considering the Y_i displacement of the detector, comparing it to the ordinate of the point source. A logical branching loop analyzes the situation as falling into one of the following categories:

Case	Comment
1. $+Y_{SRCE} < +Y_{DET}$	Source upfield
2. $+Y_{SRCE} > +Y_{DET}$	Source downfield
3. $-Y_{SRCE} > -Y_{DET}$	Detector upfield
4. $-Y_{SRCE} < -Y_{DET}$	Source upfield
5. $-Y_{SRCE} > -Y_{DET}$	Detector downfield
6. $Y_{SRCE} = 0, +Y_{DET}$	Source upfield
7. $+Y_{SRCE}, Y_{DET} = 0$	Source downfield
8. $Y_{SRCE} = 0, Y_{DET} = 0$	Source, detector on X axis

Case	Comment
9. $Y_{SRCE} = 0, -Y_{DET}$	Detector upfield
10. $-Y_{SRCE}, Y_{DET} = 0$	Detector downfield
11. $-Y_{SRCE} = -Y_{DET}$	Detector & source aligned
12. $+Y_{SRCE} = +Y_{SRCE}$	Detector & source aligned
13. $+Y_{SRCE}, -Y_{DET}$	Source downfield

Each of these categories elicits a printout in accordance with the "comment" shown to establish the logic loop used for vertical and horizontal coordinate transformation and to assist in tracing the program for trouble-shooting purposes. Each loop results in entry to a separate branch where detector and source abscissa coordinates are converted to facilitate coordinate arithmetic and translation into a second quadrant analog. This elaborate exposition of detector and source spatial relationship was mandated by the fact that each of the nine detectors in the array has a different crystal alignment. Also, each detector/source positional relationship must be translated in terms of the second quadrant curve-fit relationships that were stored in the program.

For example, if the Y coordinate of the detector were negative and the source value positive, corresponding to category 13, where the source is downfield, that case would send the program into a logic loop which recognized the location of the detector under consideration as being in Quadrants III or IV, and that of the source as in Quadrants I or II. Then, if the X coordinate of the detector were negative but greater

than the X value of the source, which for example is assumed to also be negative, the program logic narrows down the source location to Quadrant II and left of the detector, which is then recognized by the program as being in Quadrant III. As a consequence of this particular detector-to-source position relationship, the program then exchanges the derived values of R_3 and R_4 . In this illustrated instance, crystal 5 (Region 3) would receive greater illumination than crystal 1 (Region 4).

Inasmuch as the positional relationship between source and detector must be translated from Quadrants II and III to a spatially-analogous equivalent geometry in Quadrant II, so that the curve-fit expressions may be applied, the program employs a group of logical routines to produce the required coordinate axis transformations. In this particular example, a logic loop would send the program into a routine that assigns, as the "net X value", a value equal to the difference between the source and detector X coordinates and a "net Y_i " value equal to the difference between the source and detector Y_i coordinates.

For the instance where the detector is horizontally aligned with R_3 on top and R_4 on the bottom (as viewed from above), program logic ascertains that this is analogous to a Quadrant II situation when a "pseudo"* net X value is set equal to the actual net Y displacement, while the pseudo net Y_i is

* "Pseudo" refers to a transformed coordinate as opposed to the actual one.

made equal to the actual net X value. As can be seen, this transformation in effect rotates the horizontally aligned detector 90° to place it vertically in Quadrant II.

Another possible example is where the Y coordinates of the detector and source are both positive and, say, equal to each other, while detector X coordinate is negative and less than the source, which is also negative, or

$$-X_D < -X_S$$

$$+Y_D = +Y_S$$

The program initially ascertains that the detector and source are aligned, i.e., no Y_i displacement, and that either Quadrant I or Quadrant II is involved. Subsequent program analysis then establishes that both are in Quadrant II, establishing the arithmetic algorithm that must be employed in subtracting $-X_S$ from $-X_D$ to obtain net X. In this instance, the program logic does not need to transpose axes as it recognizes the case as occurring in Quadrant II. However, for the horizontally aligned crystal orientation, a transformation is produced so that the detector is rotated 90° to place its center on the +Y axis. The pseudo net X is thus the actual Y_i displacement, or zero, while the pseudo Y_i is actual net X. In this case $R_3 = R_4$, so no exchange of crystal response is required.

As may be inferred from the foregoing brief description of the synthesis program, the logic involved in developing analytic geometry programs can become complex, especially

where detector characteristics are being synthesized. All told, this program with its ancillary routines for array orientation, multiproduct development, and trace printout utilized all available locations of a 24,000-word memory. Memory size became the single most serious impediment in reaching the current phase of Mod II detector analysis, and there are subsequent investigations contemplated which must await availability of a larger computing capability. Slow printout via teletypewriter also limited the scope of the studies that could be practically undertaken. Synthesis of a source monolith comprised of 2 concentric circles, 50 mm and 25 mm respectively, with 4 radials, totalling 28 point sources, took approximately 20 hours for a 20 mm scan in 2 mm increments. A listing of the final version of the program is provided in Appendix A.

Initial investigations using the synthesis program entailed passing the array past the following configurations: a single point source at the origin; a 2.5 cm horizontal line segment centered about the origin; 2.5 cm line segments, inclined 45° and 22.5° , respectively, also centered at the origin; a 90° arc in Quadrant II, 2.5 cm in diameter, centered about the origin; and a monolithic circular source comprised of two concentric circles of radius 2.5 cm and 1.25 cm, with 4 radii, each represented by 2 points.

Results with the point source confirmed expectations that the detector is extraordinarily responsive to small positional changes. When the point source was scanned by

an array moving along the abscissa, the multiproduct factor of the upper right detector (1,3) changed from background to an 8th order-of-magnitude value within an incremental distance of less than 2 mm (Fig. 7). Each vertically-oriented detector in the array (1,3),* (3,3), (1,1), (3,1) and (2,2) displays an analogous response, but a particular output reflects that detector's relative array location in terms of actual distance from the source. For this reason, response of detector (1,3) decreases and falls to zero as the array center approaches coincidence with the source location, while the response of (1,1) (the vertically-oriented detector at the upper left) begins to increase when the array center passes over the source. The shape of the two responses is identical except for the distance displacement and the fact that one represents decreasing (1,3) detector output while the other shows an ascending response (1,1). As expected, (3,1) and (3,3) show the same product response as (1,1) and (1,3), respectively, due to their symmetrical placement with respect to a source at 0,0. Were the point not in the center with respect to the detector, product responses of (3,1) and (3,3) would not mirror (1,1) and (1,3) and the degree of displacement of the source should be deducible from the degree of dissimilarity.

The midpoint of the array always has the same coordinates as detector (2,2); hence the response curve of this detector

* Bracketed (i,j) values refer to an individual detector at row i, column j in the 3 x 3 detector array, not coordinate values.

is symmetrical about zero. The other detectors in this column, (1,2) and (3,2), are horizontally aligned and, since the point source is 38.1 mm from their respective centers, the proximal CsI(Tl) wafers completely shield the middle and distal edge NaI(Tl) crystals (corresponding to Regions 5 and 3, respectively) from the low-incidence-angle photons. Therefore, only R_4 , associated with the proximal edge NaI(Tl) crystal is illuminated and, consequently, these detectors have no multiple product output.

Detectors (2,1) and (2,3) exhibit a different response characteristic to the point source as the array moves along the abscissa and the source/horizontally-aligned detector geometry permits illumination of all crystals, the response increasing with larger X displacement. The two responses intersect at a point that coincides with the source center, as will be elaborated upon later.

Central to source position determination of this detector design is the extremely steep slope of the response rise and drop-off of vertically-aligned detectors 1,1 and 1,3.

The enhancement of the response slope results through development of the multiple product term, equivalent to $R_3^2 R_4^2 R_5^2$. It can readily be seen, from Fig. 7, that the slope of the fundamental R_3 , R_4 , and R_5 responses is not large and, moreover, that the product $(R_4 \cdot R_5)$ and $(R_3 \cdot R_5)$ produces a combined response showing accentuation of slope along with narrowing of the peaks. However, when the triple product $(R_3 \cdot R_4) \cdot (R_3 \cdot R_5) \cdot (R_4 \cdot R_5)$ is derived, the resulting com-

bined response for a detector rises and plummets suddenly when the crystals pass over the point source. This acutely sensitive response is elicited by the sudden illumination or extinction of a remote (distal) edge crystal (R_3 or R_4) as the detector approaches and then passes away from the source. A miniscule movement of the detector allows one of these edge crystals to either pass out of the shadow of its associated promontory CsI crystal or be shielded by it. Thus, a very small X displacement sends the product from zero to some very large value, even when the edge crystal output is an extremely small value. Edge crystals, therefore, function in a manner analogous to the base excitation trigger in a transistor circuit, a small signal controlling a very large output. As the detector comes upon the source, the edge crystal that is closest to the source, as well as R_5 , the center crystal, can indicate very large values which would be effectively suppressed by the zero output of the remote edge crystal, until the modulating effect results in multi-product output.

As can be noted from Figure 7 the responses of (1,3/3,3) and (1,1/3,1) are not tangential to each other at 0,0, as would be expected in this case from the foregoing analysis. This system error of approximately 6 mm is ascribed to the fact the linear ramp approximations, adopted to simplify the synthesis program in the interests of limited available computer memory, results in an abscissa intersection which is approximately 6 mm less than the experimental data would

indicate. The portion of crystal response near the abscissa is curvilinear, and would require a quadratic or perhaps a spline curve fit to accurately represent the function involved. Inasmuch as the present simplified linear approximation utilizes all available memory, further refinement of the synthesis program would necessitate a difficult, time-consuming revision of the present program to try to make room for the new instructions. It is not at all certain that this could be accomplished, given the memory constraints and limitations of the basic programming system intrinsic to the present Nova 2 computer.

When a point source is extended to become a 3 point, 45° diagonal line (Fig. 8a), the responses of detectors (1,3) and (3,3) as well as (1,1) and (3,1) no longer coincide. The decline of detector (3,3)'s response will fall below that of (1,3), while the ascending response of detector (1,1) will be below that of detector (3,1). The reason for this becomes clear from Figure 8b, which depicts the array geometry in terms of the 3-point line configuration. At the instant when the array is so positioned that the responses of detectors (1,3) and (3,3) are equal and, therefore, their response curves intersect, corresponding to $X \approx -35$, the three point sources occupy positions A-B-C relative to (1,3) and (3,3). Due to the mirror-image, 3-point symmetry viewed by (1,3) and (3,3), their respective responses are equal.

At an instant just before, the edge of detector (1,3) was slightly to the left of point C (whose relative position

was at C') the other points residing relative to the detector at B' and A', respectively. Inasmuch as point A' was in line and very close to an edge crystal of (3,3), while B' was equidistant between (3,3) and (1,3), and C' was closest to (1,3) but not in line with its edge wafer, on balance detector (3,3) should show a slightly greater output than (1,3). Examination of the dotted-line response in Figure 8a confirms this analysis.

Similarly, when the array has travelled sufficiently to the right in Figure 8b so that the line point sources are in relative positions A"-B"-C" a situation reversed from the above will have taken place. A" is no longer in line with any of the crystals of detector 3,3, while C" is closest to (1,3) and offers head-on illumination of its crystals. As theorized, the response of detector (1,3) is indeed slightly greater than that of (3,3) for these positions of the array (Fig. 8a). As the array proceeds to the right, the 3-points shift further left, points A and C becoming more and more remote from the right edge crystals of detector (1,3) and (3,3) as the interposing of the promontory CsI(Tl) crystals' shadows causes both detectors' multiproduct outputs to fall and begin to approach each other. When points A and C become completely obscured by the promontory crystals' shadow, the multiproduct terms have become equal and fall to or rise from zero at an abscissa value 6 mm less than the X coordinate of the end points of the line. The reason for the 6 mm discrepancy has already been explained, and consis-

tently appears in the synthesized responses. The foregoing description applies equally to detectors (1,1) and (3,1) which trail their counterparts (1,3/3,3) owing to their position in the 3x3 array.

The intersection of responses for horizontally-aligned detectors (2,1) and (2,3) at the origin occurs as it did for the point source and analysis of this behavior strongly suggests that these curves should intersect at an abscissa value corresponding to the center point of the sources viewed by these detectors. Thus, the X-coordinate of response intersection indicates the middle of the source configuration as it appears to the array scanning along the abscissa. Horizontally-aligned detectors (1,2) and (3,2) are similar but provide slowly-varying responses that yield similar symmetry information, as can be seen. Referring to Figure 8a and 7 when the array is situated to the left of the line points, point B is equidistant from detectors (1,2) and (3,2) but point A is relatively closer to detector (3,2) while C is farther from detector (1,2). On balance, detector (3,2) therefore has more counts than (1,2) as the array approaches the line source. When the array center is located symmetrically over the sources, both detectors have equal responses, corresponding to the intersection point. Upon the array's proceeding further to the right, the relative position of detectors (1,2) and (3,2) is such that the illumination picture becomes reversed, (1,2) being illuminated more strongly by point C than is the case with (3,2) by point A which has passed to

the left. Hence, the response of detector (1,2) is on the ascendancy, while (3,2) declines.

Further insight as to the behavior of the 3x3 array may be gleaned from review of Fig. 8(c), which depicts the background-corrected responses of each recessed crystal in a 9-detector array when illuminated by variously positioned single or multiple point sources. Inspection of 8(C-1) reveals that a characteristic pattern of individual crystal responses exists for the single point sources and its approximate location could, in fact, be derived from the crystal responses. The highest almost equal counts, 131, 130, and 126 are observed in the 3 crystals whose confluence is approximately over the point. The marked falloff of counts in the other crystals, and their pattern of change serves to locate the approximate position of the point source under the array.

Similarly, the crystal responses in 8C-2) indicate the approximate source location, i.e., the intersection of crystals having the greatest, almost equal counts, 132 and 128. Thus, it can be seen that the recessed crystal responses alone, without benefit of multiproduct development, can also provide meaningful data.

A 3-point line segment (Fig. 8C-3) results in an understandably more complex distribution of counts among the crystals but a consistent pattern nevertheless emerges which approximately locates the position of the line segment under the array. The very low counts observed in crystals along

the top and middle left and right sectors of the array, along with the highest counts being noted in the edge crystal of (2,2) and those of (3,2) effectively brackets the general location of the line segment.

Similarly, the position of the 3-point line segment in Fig. 8(C-4) becomes apparent in considering the distribution of counts among the recessed crystals. Crystals having the highest counts again are clustered around the configuration of point sources.

It seems possible that such primary crystal data might also contribute significantly to the process of decoding responses of a multi-detector array into a mosaic of constituent individual points that define the shape and features of the sources.

Inspection of Figure 9, depicting a 3-point line inclined 22.5° , reveals response patterns that bear obvious similarities to Figure 8a (45°). Responses (1,3) and (3,3) are displaced, as before, but the gap is reduced. This can be expected since the deviation of these responses stems from the inclined configuration of the sources, such that one or the other line end points will favor detector (1,3) or (3,3) depending upon array position. Therefore, as the configuration more and more approaches the horizontal, this illumination imbalance condition is lessened. Similarly, as the angle of inclination increases beyond 45° , the illumination received by detectors (1,3) and (3,3) becomes more equivalent until, at 90° , it is equal for both and the gap again disappears.

The extent of the separation between the two responses could therefore be an indication of the angularity of the source edge. This is based on the premise that activity distributed beyond, as would be encountered with an organ, for instance, will affect the magnitude of the responses but not their geometric relationships.

Studying the responses for detectors (1,2) and (3,2), it will be noted that both the separation and the degree of curvature are reduced as the line approaches the horizontal. At a critical angle, θ_c , which positions the end points sufficiently far from the remote edge crystals of (1,2) and (3,2) their illumination will cease due to promontory crystal eclipse and the two response curves will abruptly disappear. In the instance depicted, this extinction angle will be approximately 17.7° .

As the slope of the line sources increases beyond 45° , the extent of the separation between the two detectors' response curves again decreases but, in this case, the degree of curvature becomes more pronounced and greater in magnitude. This circumstance is analogous to the detector (1,2/3,2) response obtained with the circular source (Fig. 10).

If the responses for detectors (2,1) and (2,3) are compared for the 45° and 22.5° inclined lines, it is evident that the maximi are different. The end points of the 45° line are more displaced from these detectors than is the case with 22.5° , hence the latter circumstance elicits

responses of greater magnitude. The two inclined lines produce slight differences in the response of detector (2,2) at the center of the array.

The 45° inclined line places the end points of the line closer to the center line of detector (2,2) in comparison with the 22.5° line. Therefore, these points will better illuminate vertically-aligned detector (2,2) and its peak will therefore be higher. Moreover, the width of the response will be narrower, reflecting the smaller displacement of the end points from the center. By contrast, the less steep 22.5° line with its greater end-point displacement along the abscissa will produce a smaller, more broadened response.

A circular source 5 cm in diameter was represented by 2 concentric circles of 5 and 2.5 cm dia., the former with source points 0° , 30° , 90° and continuing around the periphery in 30° intervals, while the latter entailed points at 0° , 15° , 45° , 75° , 105° , etc. This arrangement avoided coincidence of points on the inner and outer circles except on the major axes where points at 5 and 2.5 cm were provided, 28 sources in all. This stylistic depiction of a round source was necessitated by both the limitations in computer memory and the desire to reduce running time by representing the shape with the smallest number of source points that would be consistent with the desired accuracy.

The detector response patterns which were developed are shown in Figure 10. As was the case with the previous array syntheses, the responses of detectors (1,3/3,1) and (1,3/3,3)

define the edges of the source, subject to the 6 mm systematic error already described. In an interval of 2 mm their responses change from zero (background) to approximately 5.6×10^{11} . The responses of detectors (1,3) and (3,3) or (1,1) and (3,1) are not displaced since the circle symmetry does not favor an upper or lower detector at any array location, as was the case with the inclined line sources. The responses of detectors (2,3) and (2,1) again intersect at an abscissa value corresponding to the center of the source configuration, or 0,0. As has been mentioned, the responses of detectors (1,2) and (3,2) coalesce and a more peaked curve is obtained which is symmetrical over the source center. Responses of detector (2,2) demonstrate the symmetry of the source configuration, and falls to zero at equally distant points from the outside of the source. It should be noted that detector (2,2) behaves identically to any other vertically-aligned detector, and the sudden increase in its response from background to a very large value could be used to locate the edge of a source in the same manner as with detectors (1,1/3,1) and (1,3/3,3).

There are interesting possibilities that intersections between the response curves may provide significant information regarding the shape and location of the source. For example, it can be seen that the intersections of detectors (2,3) with (1,1/3,1) and (2,1) with (1,3/3,3) correspond to the two edges of the source less 6 mm, as indicated by the responses of detectors (1,1) and (1,3) dropping to zero.

When these intersections are examined for the 45° inclined line, response of detectors (1,3) with (2,1) corresponds to one end of the line, while (2,3) with (3,1) is aligned with the other end. In the instance of the 22.5° line, it is the intersection of detector (2,1) response with that of (3,3) that matches the one end, and (2,3) with (1,1) that is aligned with the other. These correspondences do not seem to be coincidences but additional analyses in terms of differently dimensioned simulated sources, other configurations, and varied asymmetries, will be needed before the full significance of these intersections can be assessed.

Summing up, the various syntheses of point, line and circular sources demonstrate the high sensitivity of the detector to changes in source position, in terms of the ascending or descending edge of the response curve. It would also appear the individual detector response characteristics individually and through their intersections can also yield considerable information regarding source shape and symmetry about the abscissa and ordinate axes. Although depictions thus far have been confined to displacement along the abscissa, array movement along the ordinate will provide analogous information and thus fully define a plane figure. An obvious parallel exists for Z-axis movement, thereby providing three-dimensional data.

TABLE I
FINAL SUMMARY OF CRYSTAL WAFER MEASUREMENTS

	88 KeV		22 KeV		88 KeV
	Center	Cts.	Center	Cts.	Resol.
	Channel	(450 s)	Channel	(450 s)	(%)
<u>4.5 mm</u>					
End (midpt.)	297	1330	77	33242	19
5 mm (edge)	295	1326	75	31440	20
10 mm (edge)	293	1314	75	30938	20
18 mm (edge)	299	1297	77	31879	20
23 mm (edge)	306	1321	79	31561	19.5
30 mm (edge)	321	1327	82	29778	19.4
<u>6.5 mm</u>					
End (midpt.)	298	1573	77	36960	18
5 mm (edge)	297	1537	76	37740	18.3
10 mm (edge)	295	1548	76	39420	17.6
18 mm (edge)	297	1525	76	38460	18
23 mm (edge)	300	1510	77	37702	17.2
30 mm (edge)	311	1415	80	37457	18

TABLE II
TABULATION OF ADJUSTED REGIONS

<u>R₃ Low</u> (CPS)	<u>Y_i</u> (mm)	<u>M</u>	<u>Int.</u>	<u>R₃ High</u> (CPS)	<u>Y_i</u> (mm)	<u>M</u>	<u>Int.</u>
3.2x+100.4	0	3.2	100.4	-3.8x+238.0	0	-3.8	238.0
3.25x+99.4	5.5	3.25	99.4	-3.9x+241.0	5.5	-3.9	241.0
3.2x+96.5	16.5	3.2	96.5	-3.7x+231.0	16.5	-3.7	231.0
3.0x+95.5	22.0	3.0	95.5	-3.6x+223.0	22.0	-3.6	223.0
2.0x+69.5	50.5	2.0	69.5	-2.7x+162.0	50.5	-2.7	162.0
1.1x+40.5	79.0	1.1	40.5	-1.6x+94.0	79.0	-1.6	94.0
0.78x+26.4	95.5	0.78	26.4	-0.92x+58.6	95.5	-0.92	58.6
0.49x+16.0	115.5	0.49	16.0	-0.6x+37.4	115.5	-0.6	37.4
<u>R₄ Low</u> (CPS)	<u>Y_i</u> (mm)	<u>M</u>	<u>Int.</u>	<u>R₄ High</u> (CPS)	<u>Y_i</u> (mm)	<u>M</u>	<u>Int.</u>
3.8x+238.0	0	3.8	238.0	-3.2x+100.4	0	-3.2	100.4
3.9x+241.0	5.5	3.9	241.0	-3.25x+99.4	5.5	-3.25	99.4
3.7x+231.0	16.5	3.7	231.0	-3.2x+96.5	16.5	-3.2	96.5
3.6x+223.0	22.0	3.6	223.0	-3.0x+95.5	22.0	-3.0	95.5
2.7x+162.0	50.5	2.7	162.0	-2.0x+69.5	50.5	-2.0	69.5
1.6x+94.0	79.0	1.6	94.0	-1.1x+40.5	79.0	-1.1	40.5
0.92x+58.6	95.5	0.92	58.6	-0.78x+26.4	95.5	-0.78	26.4
0.6x+37.4	115.5	0.6	37.4	-0.49x+16.0	115.5	-0.49	16.0

TABLE II

TABULATION OF ADJUSTED REGIONS (Cont'd)

<u>R₅ Low</u> (CPS)	<u>Y_i</u> (mm)	<u>M</u>	<u>Int.</u>	<u>R₅ High</u> (CPS)	<u>Y_i</u> (mm)	<u>M</u>	<u>Int.</u>
3.3x+157.0	0	3.3	157.0	-3.3x+157.0	0	-3.3	157.0
3.27x+156.0	5.5	3.27	156.0	-3.27x+156.0	5.5	-3.27	156.0
3.25x+153.0	16.5	3.25	153.0	-3.25x+153.0	16.5	-3.25	153.0
3.3x+150.0	22.0	3.2	150.0	-3.3x+150.0	22.0	-3.3	150.0
2.3x+106.0	50.5	2.3	106.0	-2.3x+106.0	50.5	-2.3	106.0
1.4x+60.0	79.0	1.4	60.0	-1.4x+60.0	79.0	-1.4	60.0
0.9x+40.0	95.5	0.9	40.0	-0.9x+40.0	95.5	-0.9	40.0
0.51x+23.8	115.5	0.51	23.8	-0.51x+23.8	115.5	-0.51	23.8

Figure 1. Isometric View of Detector

approximate masking position

Plan View

R.M.T.

Side View

Isometric View

Figure 2. Multiple Peak Output of Detector Elements

-1.3 -

1/P1

CL= 1436 LT= 1410

16304FS

107.0

WAFER #1 NAI (L)	WAFER #2 CsI (L)	WAFER #3 NAI (C)	WAFER #4 CsI (R)	WAFER #5 NAI (R)
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Figure 3. Peak Height Change versus Interaction Site

Center Channel Displacement vs. Interaction Site

Figure 4. R_3 , R_4 , R_5 Response versus Detector Position

	NaI	CsI	NaI	CsI	NaI
	R_3		R_5		R_4

Figure 5. Configuration of 9 Detector (3x3) Array

Figure 6. Representative Synthesis Output

STATION NO. - 1
DET. [3 3]X= 8.1 Y=-38.1
SRCE X=-23.05 SRCE Y=-9.62
J[Q]= 0

NET Y= 28.48 D DF24
NET X= 31.15 S. L QIII D. + QIV[6835]
R-3= 105.485 (R-3 & R-4 EXCHANGED TO MAKE R-3 > R-4)
TOTAL R-3= 105.485
R-4= 5.70157 (R-3 & R-4 EXCHANGED)
TOTAL R-4= 5.70157
R-5= 44.6332 (R-5 LOW FOR Y<50.5)
TOTAL R-5= 44.6332

DET. [3 3]X= 8.1 Y=-38.1
SRCE X= 0 SRCE Y= 0
J[Q]= 0

NET Y= 38.1 S DF
NET X= 8.1 S. ORIG D. + QIV[3985]
R-3= 104.221 (R-3 & R-4 EXCHANGED TO MAKE R-3 > R-4)
TOTAL R-3= 209.706
R-4= 63.7614 (R-3 & R-4 EXCHANGED)
TOTAL R-4= 69.4629
R-5= 106.676 (R-5 LOW FOR Y<50.5)
TOTAL R-5= 151.309

DET. [3 3]X= 8.1 Y=-38.1
SRCE X= 23.05 SRCE Y= 9.62
J[Q]= 0

NET Y= 47.72 S DF35
NET X= 14.95 [4400]
R-3= 42.4664 (LOW, Y<50.5)
TOTAL R-3= 252.172
R-4= 97.0683 (R-4 PLATEAU FOR Y<=50.5)
TOTAL R-4= 166.531
R-5= 75.3822 (R-5 LOW FOR Y<50.5)
TOTAL R-5= 226.691

R3T X R4T = 41994.5
R3T X R5T = 57165.1
R4T X R5T = 37751.1
(R3T X R4T) (R3T X R5T) = 2.40062E+9
(R3T X R4T) (R4T X R5T) = 1.58534E+9
(R3T X R5T) (R4T X R5T) = 2.15805E+9
(R3T X R4T) (R3T X R5T) (R4T X R5T) = 9.06261E+13

STATION NO. - 2
DET. [1 1]X=-66.1 Y= 38.1
SRCE X=-23.05 SRCE Y=-9.62
J[Q]= 0

NET Y= 47.72 DET DF25
NET X= 43.05 S. R+ QIII D. QIII[7935]
R-3= 0
TOTAL R-3= 0
R-4= 48.5594 (R-4 LOW FOR Y<50.5)
TOTAL R-4= 48.5594
R-5= 6.60831 (R-5 LOW FOR Y<50.5)
TOTAL R-5= 6.60831

DET. [1 1]X=-66.1 Y= 38.1
SRCE X= 0 SRCE Y= 0
J[Q]= 0

Figure 7. Array Response to Point Source as a Function
 of Position

Figure 8a. Array Response to 45° Line Segment as a
Function of Position

Multiple Product Response

Figure 8b. Relative Position of 3 Point Line Segment
with Respect to Array Detectors

Figure 8c. Individual Crystal Responses to Various
Source Configurations

1

	(1,1)	(1,2)	(1,3)	
	(3)	(3)	0	
0	(5)	(5)	0	
		(4)	15	
		(4)	24	
	32		84	
			48	
			22	
(2,1)	62	52	102	(2,3)
			130	
	88		126	
		131		
0		86	128	
0			76	
	31		29	
		37		
	(3,1)	(3,2)	(3,3)	

2

					29				
0		0	0		59		59		
					92			109	128
	42							132	
								96	
	27	0	0	42				45	
	17								
					11				
0		0	0		0		41	70	84
					0				
					0				

3

					29				
0		0	15		80	222	267	240	
					194				
	123						272		
	150	52	150	284			321		
	153						271		
					220				
0		31			107	265	254	184	
					37				

4

					35				
0	21	86			102	271	200	107	
					233				
	170						337		
	211	143	280	349			299		
	205						180		
					243				
0	34	122			115	61	161	81	
					37				

Figure 9. Array Response to 22.5% Line Segment as
a Function of Position

Multiple Product Response

Figure 10. Array Response to a Circular Source Con-
figuration as a Function of Position

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35 PRINT "NET X=";N[Q];"S+R35 QII DQIV"
36 GOTO 2079
37 DIM S[56]
38 DIM C[54]
39 LET Q= 0
40 LET U= 0
41 LET W= 0
42 DIM X[10]
43 DIM Y[10]
44 DIM A[56]
45 DIM O[56]
46 DIM N[56]
47 DIM J[10]
48 LET R6= 0
49 LET R7= 0
50 LET R8= 0
51 GOTO 72
52 PRINT "ARRAY CTR: X, Y ?"
53 INPUT X[Q],Y[Q]
54 PRINT ",X, Y[";W;U;"]"
55 PRINT "# SRCE. ?"
56 INPUT B
57 PRINT
58 LET C=1
59 LET B1=B
60 GOTO 138
61 PRINT "CTR. DET. V=0 OR H=90 ?"
62 INPUT V
63 PRINT
64 PRINT "DET. INCR. ?"
65 INPUT D
66 LET F1=X[Q]
67 LET F2=Y[Q]
68 GOTO 146
69 LET J[Q]=V
70 LET V=V1
71 GOTO 75
72 LET G=G+1
73 PRINT "STATION NO. - ";G
74 GOTO 52
75 LET X[Q]=F1+(-38.1)
76 LET Y[Q]=F2+38.1
77 LET U=U+1
78 PRINT
81 LET W=W+1
84 IF W=4 GOTO 106
85 IF W>1 GOTO 101
86 LET F3=X[Q]
87 LET F4=Y[Q]
88 PRINT "DET. [";W;U;"]";"X=";X[Q];"Y=";Y[Q];
89 PRINT
94 PRINT "SRCE X=";A[Q];"SRCE Y=";O[Q]
96 PRINT "J[Q]=";J[Q]
97 PRINT
98 GOTO 2200
101 LET X[Q]=F3
102 LET Y[Q]=F4-38.1
103 LET A[Q]=S[C]
104 LET O[Q]=S[C+1]
105 GOTO 160
106 LET U=U+1
107 IF U=4 GOTO 122
108 IF U=3 GOTO 115
```

```

107 IF U=3 GOTO 115
108 IF U=3 GOTO 115
109 LET X[Q]=F1+(D*(G-1))
110 LET Y[Q]=F2+38.1
111 LET W=1
113 GOTO 129
115 LET X[Q]=F3+38.1
6 LET Y[Q]=F2+38.1
117 LET W=1
119 GOTO 129
122 LET Q= 0
123 LET G=G+1
124 LET X[Q]=F1+(D*(G-1))-38.1
125 LET Y[Q]=F2+38.1
126 LET W=1
127 LET U=1
128 GOTO 133
129 LET R6= 0
130 LET R7= 0
131 LET R8= 0
132 GOTO 160
133 PRINT "STATION NO. - ";G
134 GOTO 86
135 PRINT "NET X=";N[Q];"S+L135 ALLQIV"
136 GOTO 2079
138 PRINT "SRCE. # -";(B-(B1-1));"X, Y?"
139 INPUT S[C],S[C+1]
140 PRINT "X, Y [";(C);(C+1);"]"
142 LET B1=B1-1
143 IF B1= 0 GOTO 61
144 LET C=C+2
145 GOTO 138
146 LET B1=B
147 LET C=1
148 GOTO 150
149 LET C=C+2
150 LET A[Q]=S[C]
151 LET O[Q]=S[C+1]
152 LET B1=B1-1
154 IF W+U= 0 GOTO 69
155 GOTO 78
160 IF G=15 GOTO 162
161 GOTO 165
162 STOP
165 IF U>1 GOTO 175
166 IF W>1 GOTO 175
167 LET V1=J[Q]
168 GOTO 133
175 IF V1= 0 GOTO 180
176 LET V1= 0
177 LET J[Q]=V1
178 GOTO 133
180 LET V1=90
181 LET J[Q]=V1
182 GOTO 133
235 PRINT "NET X=";N[Q];"S AL235 ALLQIV"
236 GOTO 3736
237 IF B1= 0 GOTO 255
8 IF B1> 0 GOTO 245
245 LET C=C+2
246 LET A[Q]=S[C]
247 LET O[Q]=S[C+1]
248 LET B1=B1-1
249 LET J[Q]=V1
250 GOTO 88

```

```

255 LET R6= 0
256 LET R7= 0
257 LET R8= 0
258 IF (W-3)+(U-3)= 0 GOTO 260
259 GOTO 146
260 LET B1=B
261 LET C=1
262 LET A[Q]=S[C]
263 LET O[Q]=S[C+1]
264 LET B1=B1-1
265 LET J[Q]=V1
266 GOTO 122
335 PRINT "NET X=";N[Q];"S,R335 QIV"
336 GOTO 4590
535 PRINT "NET X=";N[Q];"S,L535"
536 GOTO 2079
635 PRINT "NET X=";N[Q];"S,AL635 QII"
636 GOTO 3736
735 PRINT "NET X=";N[Q];"SRCE. R -X AXIS [735]"
736 GOTO 4590
835 PRINT "NET X=";N[Q];"S,L835 QII D QI"
836 GOTO 2079
935 PRINT "NET X=";N[Q];"S,R935 QI"
936 GOTO 4590
1035 PRINT "NET X=";N[Q];"SRCE. -X AXIS DET. Q I[1035]"
1036 GOTO 2079
1135 PRINT "NET X=";N[Q];"SRCE. AT ORIG DET. AL Y AXIS[1135]"
1136 GOTO 3736
1235 PRINT "NET X=";N[Q];"S. ORIG D. L QII[1235]"
1236 GOTO 4590
1323 GOTO 86
1335 PRINT "NET X=";N[Q];"S. +X AXIS D. QII[1335]"
1336 GOTO 4590
1435 PRINT "NET X=";N[Q];"S. ORIG D. QI[1435]"
1436 GOTO 2079
1535 PRINT "NET X=";N[Q];"SRCE. +X AXIS DET R QI[1535]"
1536 GOTO 2079
1635 PRINT "NET X=";N[Q];"SRCE. ON X AXIS, ALND. ALL Q I"
1636 GOTO 3736
1735 PRINT "NET X=";N[Q];"SRCE R X AXIS ALL QI[1735]"
1736 GOTO 4590
1900 GOTO 1901
1901 DIM X[2]
1902 DIM Y[2]
1903 DIM A[2]
1904 DIM O[2]
1905 DIM N[2]
1906 DIM H[2]
1907 DIM J[2]
1908 LET R6= 0
1909 LET R7= 0
1910 LET R8= 0
1911 STOP
1912 GOTO 1913
1913 PRINT "DETECTOR X, Y?"
1915 INPUT X[Q],Y[Q]
1919 PRINT ",X, Y[";Q;"]"
1920 PRINT "SOURCE X, Y?"
1925 INPUT A[Q],O[Q]
1929 PRINT ",SOURCE X, Y[";Q;"]"
1930 PRINT "V=0 OR H=90 ?"
1931 INPUT J[Q]
1932 PRINT

```

```

1933 GOTO 2200
1935 LET Q= 0
1936 END
1937 IF Q=11 GOTO 1946
1938 LET Q=Q+1
1939 PRINT "STATION NO. - ";Q
1940 GOTO 1913
1941 GOTO 1937
1946 PRINT "RE-INITIATE"
2034 PRINT "NET Y=";H(Q);"DET. DWNFLD.[2034]"
2035 IF X(Q)> 0 GOTO 2055
2037 IF X(Q)= 0 GOTO 2047
2038 IF A(Q)> 0 GOTO 2070
2040 IF A(Q)= 0 GOTO 2065
2041 LET N(Q)=X(Q)-A(Q)
2042 IF N(Q)> 0 GOTO 4235
2043 IF N(Q)= 0 GOTO 4335
2044 LET N(Q)=-1*(X(Q)-A(Q))
2045 GOTO 4435
2047 IF A(Q)= 0 GOTO 2060
2048 IF A(Q)> 0 GOTO 2053
2049 LET N(Q)=-(A(Q))
2050 IF J(Q)= 0 GOTO 3635
2051 GOTO 2095
2053 LET N(Q)=A(Q)-X(Q)
2054 GOTO 4535
2055 IF A(Q)> 0 GOTO 2085
2056 IF A(Q)= 0 GOTO 2074
2057 LET N(Q)=X(Q)-A(Q)
2058 GOTO 4835
2060 LET N(Q)= 0
2061 GOTO 3935
2065 LET N(Q)=-X(Q)
2066 GOTO 4135
2070 LET N(Q)=A(Q)-X(Q)
2072 GOTO 4035
2074 LET N(Q)=X(Q)
2075 GOTO 4735
2079 GOTO 2080
2080 IF J(Q)= 0 GOTO 3636
2081 LET Z=(N(Q))
2082 LET L=-(H(Q))
2083 GOTO 3638
2085 LET N(Q)=X(Q)-A(Q)
2086 IF N(Q)> 0 GOTO 3635
2088 IF N(Q)= 0 GOTO 1735
2090 LET N(Q)=A(Q)-X(Q)
2092 GOTO 3835
2095 LET Z=N(Q)
2096 LET L=-(H(Q))
2097 PRINT "NET X=";N(Q);"SRCE. 1L [2097]"
2098 GOTO 3538
2134 PRINT "NET Y=";H(Q);"S. DWNFLD[2134]"
2135 IF X(Q)> 0 GOTO 2155
2137 IF X(Q)= 0 GOTO 2147
2138 IF A(Q)> 0 GOTO 2170
2140 IF A(Q)= 0 GOTO 2165
2141 LET N(Q)=X(Q)-A(Q)
2142 IF N(Q)> 0 GOTO 5235
2143 IF N(Q)= 0 GOTO 5335
2144 LET N(Q)=-1*(X(Q)-A(Q))
2145 GOTO 5435
2147 IF A(Q)= 0 GOTO 2160
2148 IF A(Q)> 0 GOTO 2153

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2150 GOTO 5635
2153 LET N[Q]=A[Q]-X[Q]
2154 GOTO 5535
2155 IF A[Q]> 0 GOTO 2185
2156 IF A[Q]= 0 GOTO 2174
2157 LET N[Q]=X[Q]-A[Q]
2158 GOTO 5835
2160 LET N[Q]== 0
2161 GOTO 4935
2165 LET N[Q]=-X[Q]
2166 GOTO 5135
2170 LET N[Q]=A[Q]-X[Q]
2172 GOTO 5035
2174 LET N[Q]=X[Q]
2175 GOTO 5735
2185 LET N[Q]=X[Q]-A[Q]
2186 IF N[Q]> 0 GOTO 5935
2188 IF N[Q]= 0 GOTO 6035
2190 LET N[Q]=A[Q]-X[Q]
2192 GOTO 6135
2199 GOTO 2200
2200 IF Y[Q]> 0 GOTO 2300
2205 IF Y[Q]= 0 GOTO 2235
2210 IF O[Q]> 0 GOTO 2400
2211 IF O[Q]= 0 GOTO 2375
2215 LET H[Q]=Y[Q]-O[Q]
2220 IF H[Q]> 0 GOTO 2634
2222 IF H[Q]= 0 GOTO 3234
2223 LET H[Q]=-1*(Y[Q]-O[Q])
2225 GOTO 2434
2234 PRINT "NET Y=";H[Q];" DET DF22"
2235 IF O[Q]= 0 GOTO 2265
2240 IF O[Q]> 0 GOTO 2280
2245 LET H[Q]=-O[Q]
2250 GOTO 3134
2265 LET H[Q]= 0
2270 GOTO 2934
2280 LET H[Q]=O[Q]-Y[Q]
2285 GOTO 2834
2300 IF O[Q]> 0 GOTO 2350
2305 IF O[Q]= 0 GOTO 2335
2310 LET H[Q]=Y[Q]-O[Q]
2315 GOTO 2534
2335 LET H[Q]=Y[Q]
2340 GOTO 2734
2350 LET H[Q]=Y[Q]-O[Q]
2355 IF H[Q]> 0 GOTO 2034
2357 IF H[Q]= 0 GOTO 3334
2358 LET H[Q]=O[Q]-Y[Q]
2360 GOTO 2134
2375 LET H[Q]=-Y[Q]
2380 GOTO 3034
2400 GOTO 2410
2410 LET H[Q]=O[Q]-Y[Q]
2415 GOTO 3534
2434 PRINT "NET Y=";H[Q];"D DF24"
2435 IF X[Q]> 0 GOTO 2455
2437 IF X[Q]= 0 GOTO 2447
2438 IF X[Q]> 0 GOTO 2470
2440 IF A[Q]= 0 GOTO 2465
2441 LET N[Q]=X[Q]-A[Q]
2442 IF N[Q]> 0 GOTO 6335
2443 IF N[Q]= 0 GOTO 6435

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2444 LET N[Q]=-1*(X[Q]-A[Q])
2445 GOTO 6535
2447 IF A[Q]= 0 GOTO 2460
448 IF A[Q]> 0 GOTO 2453
2449 LET N[Q]=-A[Q]
2450 GOTO 6635
2453 LET N[Q]=A[Q]-X[Q]
2454 GOTO 6735
2455 IF A[Q]> 0 GOTO 2485
2456 IF A[Q]= 0 GOTO 2474
2457 LET N[Q]=X[Q]-A[Q]
2458 GOTO 6835
2460 LET N[Q]= 0
2461 GOTO 6935
2465 LET N[Q]=-X[Q]
2466 GOTO 7035
2470 LET N[Q]=A[Q]-X[Q]
2472 GOTO 7135
2474 LET N[Q]=X[Q]
2475 GOTO 7235
2485 LET N[Q]=X[Q]-A[Q]
2486 IF N[Q]> 0 GOTO 7335
2488 IF N= 0 GOTO 7435
2490 LET N[Q]=A[Q]-X[Q]
2492 GOTO 7535
2534 PRINT "NET Y=";H[Q];" DET DF25"
2535 IF X[Q]> 0 GOTO 2555
2537 IF X[Q]= 0 GOTO 2547
2538 IF A[Q]> 0 GOTO 2570
2540 IF A[Q]= 0 GOTO 2565
2541 LET N[Q]=X[Q]-A[Q]
2542 IF N[Q]> 0 GOTO 7735
2543 IF N[Q]= 0 GOTO 7835
2544 LET N[Q]=-1*(X[Q]-A[Q])
2545 GOTO 7935
2547 IF A[Q]= 0 GOTO 2560
2548 IF A[Q]> 0 GOTO 2553
2549 LET N[Q]=-A[Q]
2550 GOTO 8035
2553 LET N[Q]=A[Q]-X[Q]
2554 GOTO 8135
2555 IF A[Q]> 0 GOTO 2585
2556 IF A[Q]= 0 GOTO 2574
2557 LET N[Q]=X[Q]-A[Q]
2558 GOTO 8235
2560 LET N[Q]= 0
2561 GOTO 8335
2565 LET N[Q]=-X[Q]
2566 GOTO 8435
2570 LET N[Q]=A[Q]-X[Q]
2572 GOTO 8535
2574 LET N[Q]=X[Q]
2575 GOTO 8635
2585 LET N[Q]=X[Q]-A[Q]
2586 IF N[Q]> 0 GOTO 8735
2588 IF N[Q]= 0 GOTO 8835
2590 LET N[Q]=A[Q]-X[Q]
2592 GOTO 8935
2634 PRINT "NET Y=";H[Q];" DET DF26"
2635 IF X[Q]> 0 GOTO 2655
2637 IF X[Q]= 0 GOTO 2647

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2640 IF A[Q]= 0 GOTO 2665
2641 LET N=X[Q]-A[Q]
2642 IF N[Q]> 0 GOTO 9135
2643 IF N[Q]= 0 GOTO 9235
2644 LET N[Q]=-1*(X[Q]-A[Q])
2645 GOTO 9335
2647 IF A[Q]= 0 GOTO 2660
2648 IF A[Q]> 0 GOTO 2653
2649 LET N[Q]=-A[Q]
2650 GOTO 9435
2653 LET N[Q]=A[Q]-X[Q]
2654 GOTO 9535
2655 IF A[Q]> 0 GOTO 2685
2656 IF A[Q]= 0 GOTO 2674
2657 LET N[Q]=X[Q]-A[Q]
2658 GOTO 9635
2660 LET N[Q]= 0
2661 GOTO 9735
2665 LET N[Q]=-X[Q]
2666 GOTO 9835
2670 LET N[Q]=A[Q]-X[Q]
2672 GOTO 9935
2674 LET N[Q]=X[Q]
2675 GOTO 35
2685 LET N[Q]=X[Q]-A[Q]
2686 IF N[Q]> 0 GOTO 135
2688 IF N[Q]= 0 GOTO 235
2690 LET N[Q]=A[Q]-X[Q]
2692 GOTO 335
2734 PRINT "NET Y=";H[Q];"DET DF27"
2735 GOTO 2736
2736 IF X[Q]> 0 GOTO 2755
2737 IF X[Q]= 0 GOTO 2747
2738 IF A[Q]> 0 GOTO 2770
2740 IF A[Q]= 0 GOTO 2765
2741 LET N[Q]=X[Q]-A[Q]
2742 IF N[Q]> 0 GOTO 535
2743 IF N[Q]= 0 GOTO 635
2744 LET N[Q]=-1*(X[Q]-A[Q])
2745 GOTO 735
2747 IF A[Q]= 0 GOTO 2760
2748 IF A[Q]> 0 GOTO 2753
2749 LET N=-A[Q]
2750 GOTO 835
2753 LET N[Q]=A[Q]-X[Q]
2754 GOTO 935
2755 IF A[Q]> 0 GOTO 2785
2756 IF A[Q]= 0 GOTO 2774
2757 LET N[Q]=X[Q]-A[Q]
2758 GOTO 1035
2760 LET N[Q]= 0
2761 GOTO 1135
2765 LET N[Q]=-X[Q]
2766 GOTO 1235
2770 LET N[Q]=A[Q]-X[Q]
2772 GOTO 1335
2774 LET N[Q]=X[Q]
2775 GOTO 1435
2785 LET N[Q]=X[Q]-A[Q]
2786 IF N[Q]> 0 GOTO 1535
2788 IF N[Q]= 0 GOTO 1635
2790 LET N[Q]=A[Q]-X[Q]
2792 GOTO 1735

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2836 IF X[Q]> 0 GOTO 2855
2837 IF X[Q]= 0 GOTO 2847
2838 IF A[Q]> 0 GOTO 2870
2840 IF A[Q]= 0 GOTO 2865
2841 LET N[Q]=X[Q]-A[Q]
2842 IF N[Q]> 0 GOTO 3750
2843 IF N[Q]= 0 GOTO 3760
2844 LET N[Q]=-1*(X[Q]-A[Q])
2845 GOTO 3770
2847 IF A[Q]= 0 GOTO 2860
2848 IF A[Q]> 0 GOTO 2853
2849 LET N[Q]=-(A[Q])
2850 GOTO 3780
2853 LET N[Q]=A[Q]-A[Q]
2854 GOTO 3790
2855 IF A[Q]> 0 GOTO 2885
2856 IF A[Q]= 0 GOTO 2874
2857 LET N[Q]=X[Q]-A[Q]
2858 GOTO 3795
2860 LET N[Q]= 0
2861 GOTO 3800
2865 LET N[Q]=-(X[Q])
2866 GOTO 3805
2870 LET N[Q]=A[Q]-X[Q]
2872 GOTO 3810
2874 LET N[Q]=X[Q]
2875 GOTO 3815
2885 LET N[Q]=X[Q]-A[Q]
2886 IF N[Q]> 0 GOTO 3820
2888 IF N[Q]= 0 GOTO 3825
2890 LET N[Q]=A[Q]-X[Q]
2892 GOTO 3830
2934 PRINT "NET Y=";H[Q]
2935 GOTO 2936
2936 IF X[Q]> 0 GOTO 2955
2937 IF X[Q]= 0 GOTO 2947
2938 IF A[Q]> 0 GOTO 2970
2940 IF A[Q]= 0 GOTO 2965
2941 LET N[Q]=X[Q]-A[Q]
2942 IF N[Q]> 0 GOTO 3840
2943 IF N[Q]= 0 GOTO 3850
2944 LET N[Q]=-1*(X[Q]-A[Q])
2945 GOTO 3860
2947 IF A[Q]= 0 GOTO 2960
2948 IF A[Q]> 0 GOTO 2953
2949 LET N[Q]=-(A[Q])
2950 GOTO 3866
2953 LET N[Q]=A[Q]-X[Q]
2954 GOTO 3870
2955 IF A[Q]> 0 GOTO 2985
2956 IF A[Q]= 0 GOTO 2974
2957 LET N[Q]=X[Q]-A[Q]
2958 GOTO 3875
2960 LET N[Q]= 0
2961 GOTO 3880
2965 LET N[Q]=-(X[Q])
2966 GOTO 3885
2970 LET N[Q]=A[Q]-X[Q]
2972 GOTO 3890
2974 LET N[Q]=X[Q]
2975 GOTO 3895
2985 LET N[Q]=X[Q]-A[Q]
2986 IF N[Q]> 0 GOTO 3900
2988 IF N[Q]= 0 GOTO 3905
2990 LET N[Q]=A[Q]-X[Q]

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```

3034 PRINT "NET Y=";H[Q];"$ DF"
3035 GOTO 3036
3036 IF X[Q]> 0 GOTO 3055
3037 IF X[Q]= 0 GOTO 3047
3038 IF A[Q]> 0 GOTO 3070
3040 IF A[Q]= 0 GOTO 3065
3041 LET N[Q]=X[Q]-A[Q]
3042 IF N[Q]> 0 GOTO 3940
3043 IF N[Q]= 0 GOTO 3945
3044 LET N[Q]=-1*(X[Q]-A[Q])
3045 GOTO 3950
3047 IF A[Q]= 0 GOTO 3060
3048 IF A[Q]> 0 GOTO 3053
3049 LET N[Q]=-(A[Q])
3050 GOTO 3955
3053 LET N[Q]=A[Q]-X[Q]
3054 GOTO 3960
3055 IF A[Q]> 0 GOTO 3085
3056 IF A[Q]= 0 GOTO 3074
3057 LET N[Q]=X[Q]-A[Q]
3058 GOTO 3965
3060 LET N[Q]= 0
3061 GOTO 3970
3065 LET N[Q]=-(X[Q])
3066 GOTO 3975
3070 LET N[Q]=A[Q]-X[Q]
3072 GOTO 3980
3074 LET N[Q]=X[Q]
3075 GOTO 3985
3085 LET N[Q]=X[Q]-A[Q]
3086 IF N[Q]> 0 GOTO 3990
3088 IF N[Q]= 0 GOTO 3995
3090 LET N[Q]=A[Q]-X[Q]
3092 GOTO 4000
3134 PRINT "NET Y=";H[Q];"DET DF"
3135 GOTO 3136
3136 IF X[Q]> 0 GOTO 3155
3137 IF X[Q]= 0 GOTO 3147
3138 IF A[Q]> 0 GOTO 3170
3140 IF A[Q]= 0 GOTO 3165
3141 LET N[Q]=X[Q]-A[Q]
3142 IF N[Q]> 0 GOTO 4040
3143 IF N[Q]= 0 GOTO 4045
3144 LET N[Q]=-1*(X[Q]-A[Q])
3145 GOTO 4050
3147 IF A[Q]= 0 GOTO 3160
3148 IF A[Q]> 0 GOTO 3153
3149 LET N[Q]=-(A[Q])
3150 GOTO 4055
3153 LET N[Q]=A[Q]-X[Q]
3154 GOTO 4060
3155 IF A[Q]> 0 GOTO 3185
3156 IF A[Q]= 0 GOTO 3174
3157 LET N[Q]=X[Q]-A[Q]
3158 GOTO 4065
3160 LET N[Q]= 0
3161 GOTO 4070
3165 LET N[Q]=-(X[Q])
3166 GOTO 4075
3170 LET N[Q]=A[Q]-X[Q]
3172 GOTO 4080
3174 LET N[Q]=X[Q]
3175 GOTO 4085
3185 LET N[Q]=X[Q]-A[Q]

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3190 LET N[Q]=A[Q]-X[Q]
3192 GOTO 4100
3234 PRINT "NET Y=";H[Q];"ND32"
3235 GOTO 3236
3236 IF X[Q]> 0 GOTO 3255
3237 IF X[Q]= 0 GOTO 3247
3238 IF A[Q]> 0 GOTO 3270
3240 IF A[Q]= 0 GOTO 3265
3241 LET N[Q]=X[Q]-A[Q]
3242 IF N[Q]> 0 GOTO 4140
3243 IF N[Q]= 0 GOTO 4145
3244 LET N[Q]=-1*(X[Q]-A[Q])
3245 GOTO 4150
3247 IF A[Q]= 0 GOTO 3260
3248 IF A[Q]> 0 GOTO 3253
3249 LET N[Q]=-(A[Q])
3250 GOTO 4155
3253 LET N[Q]=A[Q]-X[Q]
3254 GOTO 4160
3255 IF A[Q]> 0 GOTO 3285
3256 IF A[Q]= 0 GOTO 3274
3257 LET N[Q]=X[Q]-A[Q]
3258 GOTO 4165
3260 LET N[Q]= 0
3261 GOTO 4170
3265 LET N[Q]=-(X[Q])
3266 GOTO 4175
3270 LET N[Q]=A[Q]-X[Q]
3272 GOTO 4180
3274 LET N[Q]=X[Q]
3275 GOTO 4185
3285 LET N[Q]=X[Q]-A[Q]
3286 IF N[Q]> 0 GOTO 4190
3288 IF N[Q]= 0 GOTO 4195
3290 LET N[Q]=A[Q]-X[Q]
3292 GOTO 4200
3334 PRINT "NET Y=";H[Q];"ND33"
3335 GOTO 3336
3336 IF X[Q]> 0 GOTO 3355
3337 IF X[Q]= 0 GOTO 3347
3338 IF A[Q]> 0 GOTO 3370
3340 IF A[Q]= 0 GOTO 3365
3341 LET N[Q]=X[Q]-A[Q]
3342 IF N[Q]> 0 GOTO 4240
3343 IF N[Q]= 0 GOTO 4245
3344 LET N[Q]=-1*(X[Q]-A[Q])
3345 GOTO 4250
3347 IF A[Q]= 0 GOTO 3360
3348 IF A[Q]> 0 GOTO 3353
3349 LET N[Q]=-(A[Q])
3350 GOTO 4255
3353 LET N[Q]=A[Q]-X[Q]
3354 GOTO 4260
3355 IF A[Q]> 0 GOTO 3385
3356 IF A[Q]= 0 GOTO 3374
3357 LET N[Q]=X[Q]-A[Q]
3358 GOTO 4265
3360 LET N[Q]= 0
3361 GOTO 4270
3365 LET N[Q]=-(X[Q])
3366 GOTO 4275
3370 LET N[Q]=A[Q]-X[Q]
3372 GOTO 4280
3374 LET N[Q]=X[Q]

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```

3386 IF N[Q] > 0 GOTO 4290
3388 IF N[Q] = 0 GOTO 4295
3390 LET N[Q] = A[Q] - X[Q]
392 GOTO 4300
3534 PRINT "NET Y="; H[Q]; "S DF35"
3535 IF X[Q] > 0 GOTO 3555
3536 IF X[Q] = 0 GOTO 3547
3537 IF A[Q] > 0 GOTO 3570
3540 IF A[Q] = 0 GOTO 3565
3541 LET N[Q] = X[Q] - A[Q]
3542 IF N[Q] > 0 GOTO 4340
3543 IF N[Q] = 0 GOTO 4345
3544 LET N[Q] = -(X[Q] - A[Q])
3545 GOTO 4350
3547 IF A[Q] = 0 GOTO 3560
3548 IF A[Q] > 0 GOTO 3553
3549 LET N[Q] = -(A[Q])
3550 GOTO 4355
3553 LET N[Q] = A[Q] - X[Q]
3554 GOTO 4360
3555 IF A[Q] > 0 GOTO 3585
3556 IF A[Q] = 0 GOTO 3574
3557 LET N[Q] = X[Q] - A[Q]
3558 GOTO 4365
3560 LET N[Q] = 0
3561 GOTO 4370
3565 LET N[Q] = -(X[Q])
3566 GOTO 4375
3570 LET N[Q] = A[Q] - X[Q]
3572 GOTO 4380
3574 LET N[Q] = X[Q]
3575 GOTO 4385
3585 LET N[Q] = X[Q] - A[Q]
3586 IF N[Q] > 0 GOTO 4390
3588 IF N[Q] = 0 GOTO 4395
3590 LET N[Q] = A[Q] - X[Q]
3592 GOTO 4400
3635 PRINT "NET X="; N[Q]; "S L+36"
3636 LET Z = H[Q]
3637 LET L = -(N[Q])
3638 IF L >= -32.3 GOTO 3643
3639 LET R3 = 0
3640 IF J[Q] = 0 GOTO 3706
3641 PRINT "R-3="; R3
3642 GOTO 3700
3643 IF L <= 61.7 GOTO 3648
3644 LET R3 = 0
3645 IF J[Q] = 0 GOTO 3706
3646 PRINT "R-3="; R3
3647 GOTO 3700
3648 IF L >= 8.2 GOTO 3661
3651 IF Z >= 50.5 GOTO 3680
3652 LET M3 = -.00051*(Z)+2+.0022*Z+3.108
3653 LET I3 = -.0136*(Z)+2+(.0777*Z)+100.4
654 LET R3 = (M3*L)+(I3)
3656 IF J[Q] = 0 GOTO 3706
3657 PRINT "R-3="; R3; "(LOW, Y<50.5)"
3658 LET R6 = R3+R6
3659 PRINT "TOTAL R-3="; R6
3660 GOTO 3706
3661 IF L > 27.7 GOTO 3671
3662 IF Z <= 50.5 GOTO 3688

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3665 IF J[Q]= 0 GOTO 3706
3666 PRINT "R-3=";R3;"(R-3 PLATEAU FOR Y<=50.5)"
3667 LET R6=R3+R6
3668 PRINT "TOTAL R-3=";R6
3669 GOTO 3706
3671 IF Z>50.5 GOTO 3695
3672 LET M4=-.000445*(Z)+2+(.000706*Z)+3.8
3673 LET I4=-.0289*(Z)+2-(.0464*Z)+238
3674 LET R3=-(M4*L)+I4
3675 IF J[Q]= 0 GOTO 3706
3676 PRINT "R-3=";R3;"(R-3 HIGH FOR Y<=50.5)"
3677 LET R6=R3+R6
3678 PRINT "TOTAL R-3=";R6
3679 GOTO 3706
3680 LET M3=.000229*(Z-50.5)+2-(.0381*(Z-50.5))+2
3681 LET I3=.00533*(Z-50.5)+2-(1.17*(Z-50.5))+69.5
3682 LET R3=(M3)*L+I3
3683 IF J[Q]= 0 GOTO 3706
3684 PRINT "R-3=";R3;"(R-3 LOW FOR Y>50.5)"
3685 LET R6=R3+R6
3686 PRINT "TOTAL R-3=";R6
3687 GOTO 3706
3688 LET R3=.00923*(Z-50.5)+2-(1.526*(Z-50.5))+82
3690 IF J[Q]= 0 GOTO 3706
3691 PRINT "R-3=";R3;"(R-3 PLATEAU FOR Y>50.5)"
3692 LET R6=R3+R6
3693 PRINT "TOTAL R-3=";R6
3694 GOTO 3706
3695 LET M4=.000172*(Z-50.5)+2-(.0435*(Z-50.5))+2.7
3696 LET I4=.0128*(Z-50.5)+2-(2.75*(Z-50.5))+162
3697 LET R3=-(M4*L)+I4
3698 IF J[Q]= 0 GOTO 3706
3699 PRINT "R-3=";R3;"(R-3 HIGH FROM R-4 LOW FOR Y>50.5)"
3700 LET R6=R3+R6
3701 PRINT "TOTAL R-3=";R6
3705 GOTO 3706
3706 IF L>=-61.4 GOTO 3710
3707 LET R4= 0
3708 IF J[Q]= 0 GOTO 4495
3709 GOTO 4454
3710 IF L<30 GOTO 3714
3711 LET R4= 0
3712 IF J[Q]= 0 GOTO 4495
3713 GOTO 4454
3714 IF L>=-28.7 GOTO 3727
3715 IF Z>=50.5 GOTO 4469
3716 LET M4=-(.000445*(Z)+2)+(.000706*Z)+3.8
3717 LET I4=-(.0289*(Z)+2)-(.0464*(Z))+238
3718 LET R4=(M4*L)+I4
3720 IF J[Q]= 0 GOTO 4495
3721 PRINT "R-4=";R4;"(R-4 LOW FOR Y<50.5)"
3722 LET R7=R4+R7
3723 PRINT "TOTAL R-4=";R7
3724 GOTO 4497
3727 IF L>=-9.3 GOTO 4460
3728 IF Z>=50.5 GOTO 4477
3729 LET R4=-(.0167*(Z)+2)+(.00204*Z)+135
3732 IF J[Q]= 0 GOTO 4495
3733 PRINT "R-4=";R4;"(R-4 PLATEAU FOR Y<=50.5)"
3734 GOTO 4455
3735 PRINT "NET X=";N[Q];"S: AL37"
3736 GOTO 3738
3738 IF J[Q]= 0 GOTO 3742

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3740 LET Z=N[Q]
3741 GOTO 3638
3742 LET J[Q]=90
3743 LET L=N[Q]
3744 LET Z=H[Q]
3745 GOTO 3638
3750 PRINT "NET X=";N[Q];"S L DF37"
3751 GOTO 5236
3760 PRINT "NET X=";N[Q];"S AL DF37"
3761 GOTO 4936
3770 PRINT "NET X=";N[Q];"S. R QII D. -X AXIS[3770]"
3771 GOTO 5036
3780 PRINT "NET X=";N[Q];" D. ORIG S. L DWNFLD QII[3780]"
3781 GOTO 5236
3790 PRINT "NET X=";N[Q];" D. ORIG S. R DWNFLD QI[3790]"
3791 GOTO 5036
3795 PRINT "NET X=";N[Q];" S. L DWNFLD QII D +X AXIS[3795]"
3796 GOTO 5236
3800 PRINT "NET X=";N[Q];"S. Y AXIS QI D ORIG[3800]"
3801 GOTO 4936
3805 PRINT "NET X=";N[Q];"S. Y AXIS QI D -X AXIS[3805]"
3806 GOTO 5036
3810 PRINT "NET X=";N[Q];"SRCE. R DWNFLD. DET. +X AXIS[3810]"
3811 GOTO 5036
3815 PRINT "NET X=";N[Q];"S. +Y AXIS D +X AXIS[3815]"
3816 GOTO 5236
3820 PRINT "NET X=";N[Q];"S. L QI D. +X AXIS[3820]"
3821 GOTO 5236
3825 PRINT "NET X=";N[Q];"SRCE. DWNFLD. AL DET. +X AXIS[3825]"
3826 GOTO 4936
3830 PRINT "NET X=";N[Q];"SRCE. R DWNFLD. DET. +X AXIS[3830]"
3831 GOTO 5036
3835 PRINT "NET X=";N[Q];"SRCE. R [3835]"
3836 GOTO 4536
3840 PRINT "NET X=";N[Q];"S L AL -X AXIS[3840]"
3841 GOTO 3842
3842 IF J[Q]= 0 GOTO 3636
3843 LET Z=N[Q]
3844 LET L=H[Q]
3845 GOTO 3638
3850 PRINT "NET X=";N[Q];"S & D COINC -X AXIS[3850]"
3851 GOTO 3852
3852 LET L=N[Q]
3853 LET Z=H[Q]
3854 GOTO 3638
3860 PRINT "NET X=";N[Q];"S. R -X AXIS AL [3860]"
3861 GOTO 3862
3862 IF J[Q]= 0 GOTO 4596
3863 LET L=H[Q]
3864 LET Z=N[Q]
3865 GOTO 3638
3866 PRINT "NET X=";N[Q];"SRCE. -X AXIS DET. ORIG.[3866]"
3867 GOTO 3841
3870 PRINT "NET X=";N[Q];"S. +X AXIS D. ORIG[3870]"
3871 GOTO 3861
3875 PRINT "NET X=";N[Q];"S. -X AXIS D. +X AXIS[3875]"
3876 GOTO 3841
3880 PRINT "NET X=";N[Q];"SRCE. & DET. ORIG.[3880]"
3881 GOTO 3851
3885 PRINT "NET X=";N[Q];"S. ORIG D. -X AXIS[3885]"
3886 GOTO 3861
3890 PRINT "NET X=";N[Q];"S. +X AXIS D. -X AXIS[3890]"

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3895 PRINT "NET X=";N[Q];"S. ORIG DET. +X AXIS[3895]"
3896 GOTO 3841
3900 PRINT "NET X=";N[Q];"S. L +X AXIS WITH DET.[3900]"
3901 GOTO 3841
3905 PRINT "NET X=";N[Q];"S & D COINC +X AXIS[3905]"
906 GOTO 3851
910 PRINT "NET X=";N[Q];"S. R +X AXIS WITH DET[3910]"
3911 GOTO 3861
3935 PRINT "NET X=";N[Q];"S & D Y AXIS S.[3935]"
3936 GOTO 3736
3940 PRINT "NET X=";N[Q];"S. -X AXIS D. DWNFLD QIII[3940]"
3941 GOTO 5236
3945 PRINT "NET X=";N[Q];"S. -X AXIS AL DET. QIII[3945]"
3946 GOTO 4936
3950 PRINT "NET X=";N[Q];"S. R -X AXIS D. QIII[3950]"
3951 GOTO 5036
3955 PRINT "NET X=";N[Q];"S -X AXIS D. -Y AXIS[3955]"
3956 GOTO 5236
3960 PRINT "NET X=";N[Q];"S. +X AXIS D. -Y AXIS[3960]"
3961 GOTO 5036
3965 PRINT "NET X=";N[Q];"S. -Y AXIS D. QIV[3965]"
3966 GOTO 5236
3970 PRINT "NET X=";N[Q];"S. ORIG D. -Y AXIS[3970]"
3971 GOTO 4936
3975 PRINT "NET X=";N[Q];"S. ORIG D. QIII[3975]"
3976 GOTO 5036
3980 PRINT "NET X=";N[Q];"S. +X AXIS D. QIII[3980]"
3981 GOTO 5036
3985 PRINT "NET X=";N[Q];"S. ORIG D. QIV[3985]"
3986 GOTO 5236
3990 PRINT "NET X=";N[Q];"S. +X AXIS D. R. QIV[3990]"
3991 GOTO 5236
3992 GOTO 4000
3995 PRINT "NET X=";N[Q];"S. +X AXIS AL D. QIV[3995]"
3996 GOTO 4936
4000 PRINT "NET X=";N[Q];"S. R +X AXIS D. QIV[4000]"
4001 GOTO 5036
4035 PRINT "NET X=";N[Q];"S. R. QI D. QII[4035#1]"
4036 GOTO 4536
4040 PRINT "NET X=";N[Q];"S. L. QIII D -X AXIS[4040]"
4041 GOTO 5036
4045 PRINT "NET X=";N[Q];"SRCE. AL. Q III DET -X AXIS[4045]"
4046 GOTO 4047
4047 IF J[Q]=90 GOTO 3739
4048 LET J[Q]=90
4049 GOTO 3843
4050 PRINT "NET X=";N[Q];"SRCE. R. Q III DET. -X AXIS[4050]"
4051 GOTO 4590
4055 PRINT "NET =" ;N[Q];" S. L. QIII D ORIG[4055]"
4056 GOTO 5036
4060 PRINT "NET X=";N[Q];"S. R. QIV D. ORIG[4060]"
4061 GOTO 4590
4065 PRINT "NET X=";N[Q];"S. L. QIII D. +X AXIS[4065]"
4066 GOTO 5036
4070 PRINT "NET X=";N[Q];" S. AL -Y AXIS D ORIG[4070]"
4071 GOTO 4046
4075 PRINT "NET X=";N[Q];"S -Y AXIS D. -X AXIS[4075]"
4076 GOTO 4590
4080 PRINT "NET X=";N[Q];"S. R. QIV D -X AXIS[4080]"
4081 GOTO 4590
4085 PRINT "NET X=";N[Q];"S. -Y AXIS D. R +X AXIS[4085]"
4086 GOTO 5036

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4095 PRINT "NET X=";N[Q];"SRCE. AL QIV DET. +X AXIS[4095]"
4096 GOTO 4046
4100 PRINT "NET X=";N[Q];"S. R QIV D. +X AXIS[4100]"
4101 GOTO 4590
4135 PRINT "NET X=";N[Q];"S. +Y AXIS + D. QIII[4135]"
36 GOTO 4536
40 PRINT "NET X=";N[Q];"S. L AL QIII[4140]"
4141 GOTO 4142
4142 IF J[Q]=0 GOTO 3636
4143 GOTO 3863
4145 PRINT "NET X=";N[Q];"S & D COINC QIII[4145]"
4146 GOTO 3851
4150 PRINT "NET X=";N[Q];"S. R AL QIII[4150]"
4151 GOTO 4152
4152 IF J[Q]=90 GOTO 3843
4153 LET J[Q]=90
4154 GOTO 3636
4155 PRINT "NET X=";N[Q];"S. L AL D. -Y AXIS[4155]"
4156 GOTO 4141
4160 PRINT "NET X=";N[Q];"S. R AL D. -Y AXIS[4160]"
4161 GOTO 4151
4165 PRINT "NET X=";N[Q];"S. L AL QIII D QIV[4165]"
4166 GOTO 4141
4170 PRINT "NET X=";N[Q];"SRCE & DET COINCIDE -Y AXIS"
4171 GOTO 3851
4175 PRINT "NET X=";N[Q];"SRCE R -Y AXIS DET Q III"
4176 GOTO 4151
4180 PRINT "NET X=";N[Q];"S. R AL QI4 DET Q III[4180]"
4181 GOTO 4151
4185 PRINT "NET X=";N[Q];"S. -Y AXIS AL D QIV[4185]"
4186 GOTO 4141
4190 PRINT "NET X=";N[Q];"SRCE. L AL ALL QIV[4190]"
4191 GOTO 4141
4195 PRINT "NET X=";N[Q];"SRCE. & DET. COINC. QIV[4195]"
4196 GOTO 3851
4200 PRINT "NET X=";N[Q];"S. R AL ALL QIV[4200]"
4201 GOTO 4151
4235 PRINT "NET X=";N[Q];"S. L AL ALL QIII[4235]"
4236 GOTO 2079
4240 PRINT "NET X=";N[Q];"[4240#12]"
4241 GOTO 4141
4245 PRINT "NET X=";N[Q];"[4245#12]"
4246 GOTO 3851
4250 PRINT "NET X=";N[Q];"[4250]"
4251 GOTO 4151
4255 PRINT "NET X=";N[Q];"[4255]"
4256 GOTO 4141
4260 PRINT "NET X=";N[Q];"[4260]"
4261 GOTO 4151
4265 PRINT "NET X=";N[Q];"[4265]"
4266 GOTO 4141
4270 PRINT "NET X=";N[Q];"[4270]"
4271 GOTO 3851
4275 PRINT "NET X=";N[Q];"[4275]"
4276 GOTO 4151
4280 PRINT "NET X=";N[Q];"[4280]"
4281 GOTO 4151
4285 PRINT "NET X=";N[Q];"[4285]"
4286 GOTO 4141
4290 PRINT "NET X=";N[Q];"[4290]"
4291 GOTO 4141
4295 PRINT "NET X=";N[Q];"[4295]"
4296 GOTO 3851

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4335 PRINT "NET X=";N[Q];"S. AL: ALL QII[4335]"
4336 GOTO 3736
4340 PRINT "NET X=";N[Q];"[4340]"
4341 GOTO 5236
4345 PRINT "NET X=";N[Q];"[4345]"
346 GOTO 4936
4350 PRINT "NET X=";N[Q];"[4350]"
4351 GOTO 5036
4355 PRINT "NET X=";N[Q];"[4355]"
4356 GOTO 5236
4360 PRINT "NET X=";N[Q];"[4360]"
4361 GOTO 5036
4365 PRINT "NET X=";N[Q];"[4365]"
4366 GOTO 5236
4370 PRINT "NET X=";N[Q];"[4370]"
4371 GOTO 4936
4375 PRINT "NET X=";N[Q];"[4375]"
4376 GOTO 5036
4380 PRINT "NET X=";N[Q];"[4380]"
4381 GOTO 5036
4385 PRINT "NET X=";N[Q];"[4385]"
4386 GOTO 5236
4390 PRINT "NET X=";N[Q];"[4390]"
4391 GOTO 5236
4395 PRINT "NET X=";N[Q];"[4395]"
4396 GOTO 4936
4400 PRINT "NET X=";N[Q];"[4400]"
4401 GOTO 5036
4435 PRINT "NET X=";N[Q];"[4435]"
4436 GOTO 4590
4454 PRINT "R-4=";R4;
4455 LET R7=R4+R7
4456 PRINT "TOTAL R-4=";R7
4457 GOTO 4497
4460 IF Z>=50.5 GOTO 4485
4461 LET M3=-(.00051*(Z)+2)+(.0022*Z)+3.2
4462 LET I3=-(.0136*(Z)+2)+(.0777*Z)+100.4
4463 LET R4=-(M3*L)+I3
4464 IF J[Q]= 0 GOTO 4495
4465 PRINT "R-4=";R4;"(R-4 HIGH DERIVED FROM R-3 LOW FOR Y<50.5)"
4466 GOTO 4455
4469 LET M4=.000172*(Z-50.5)+2-(.0435*(Z-50.5))+2.7
4470 LET I4=.0128*(Z-50.5)+2-(2.75*(Z-50.5))+162
4471 LET R4=(M4*L)+I4
4472 IF J[Q]= 0 GOTO 4495
4473 PRINT "R-4=";R4;"(R-4 LOW FOR Y>=50.5)"
4474 GOTO 4455
4477 LET R4=.00836*(Z-50.5)+2-(1.63*(Z-50.5))+92.5
4480 IF J[Q]= 0 GOTO 4495
4481 PRINT "R-4=";R4;"(R-4 PLATEAU FOR Y>=50.5)"
4482 GOTO 4455
4485 LET M3=.000229*(Z-50.5)+2-(.0381*(Z-50.5))+2
4486 LET I3=.00533*(Z-50.5)+2-(1.17*(Z-50.5))+69.5
4487 LET R4=-(M3*L)+I3
4490 IF J[Q]= 0 GOTO 4495
4491 PRINT "R-4=";R4;"(R-4 HIGH DERIVED FROM R-3 LOW FOR Y>=50.5)"
4492 GOTO 4455
4495 GOTO 4575
4496 GOTO 4497
4497 IF L>=-45.2 GOTO 4503
4498 LET R5= 0
4499 PRINT "R-5=";R5

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4503 IF L<=47.6 GOTO 4506
4504 GOTO 4498
4506 IF L>=-7 GOTO 4519
4507 IF Z>=50.5 GOTO 4565
4508 LET M5=-(.000695*(Z)+2)+(.0153*Z)+3.3
4509 LET I5=-(.0243*(Z)+2)+(.216*Z)+157
4510 LET R5=(M5*L)+I5
4513 PRINT "R-5=";R5;"(R-5 LOW FOR Y<50.5)"
4514 GOTO 4500
4519 IF L>7.5 GOTO 4528
4520 IF Z>=50.5 GOTO 4550
4521 LET R5=-(.0168*(Z)+2)-(.0131*Z)+134
4522 PRINT "R-5=";R5;"(R-5 PLATEAU FOR Y<50.5)"
4523 GOTO 4500
4527 GOTO 4528
4528 IF Z>=50.5 GOTO 4557
4529 LET M5=-(.000695*(Z)+2)+(.0153*Z)+3.3
4530 LET I5=-(.0243*(Z)+2)+(.216*Z)+157
4531 LET R5=-(M5*L)+I5
4532 PRINT "R-5=";R5;"(R-5 HIGH FOR Y<50.5)"
4533 GOTO 4500
4534 GOTO 4535
4535 PRINT "NET X=";N[Q];"S. R+ D. Y AXIS[4535]"
4536 GOTO 4537
4537 IF J[Q]= 0 GOTO 4542
4538 LET Z=N[Q]
4539 LET L=-(H[Q])
4540 GOTO 3638
4542 LET J[Q]=90
4543 GOTO 3636
4549 GOTO 4550
4550 LET R5=(.0093*(Z-50.5)+2)-(1.66*(Z-50.5))+90.6
4551 PRINT "R-5=";R5;"(PLATEAU FOR>=50.5)"
4552 GOTO 4500
4556 GOTO 4557
4557 LET M5=(.000111*(Z-50.5)+2)-(.0347*(Z-50.5))+2.3
4558 LET I5=(.00957*(Z-50.5)+2)-(1.887*(Z-50.5))+106
4559 LET R5=-(M5*L)+I5
4560 PRINT "R-5=";R5;"(PLATEAU FOR Y>=50.5)"
4561 GOTO 4500
4564 GOTO 4565
4565 LET M5=(.000111*(Z-50.5)+2)-(.0347*(Z-50.5))+2.3
4566 LET I5=(.00957*(Z-50.5)+2)-(1.887*(Z-50.5))+106
4567 LET R5=(M5*L)+I5
4568 PRINT "R-5=";R5;"(R-5 LOW FOR Y>=50.5)"
4569 GOTO 4500
4575 GOTO 4576
4576 PRINT "R-3=";R4;"(R-3 & R-4 EXCHANGED TO MAKE R-3 > R-4)"
4577 LET R6=R4+R6
4578 PRINT "TOTAL R-3=";R6
4579 PRINT "R-4=";R3;"(R-3 & R-4 EXCHANGED)"
4580 LET R7=R3+R7
4581 PRINT "TOTAL R-4=";R7
4582 GOTO 4497
4585 PRINT
4586 GOTO 4638
4590 GOTO 4591
4591 IF J[Q]= 0 GOTO 4596
4593 LET Z=N[Q]
4594 LET L=-(H[Q])
4595 GOTO 3638
4596 LET J[Q]=90
4597 GOTO 3636

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4640 LET P1=R6*R7
4641 PRINT "R3T X R4T =";P1,
4642 PRINT
4643 LET P2=R6*R8
4644 PRINT "R3T X R5T =";P2,
4645 PRINT
4646 LET P3=R7*R8
4647 PRINT "R4T X R5T =";P3,
4648 PRINT
4649 LET P4=P1*P2
4650 PRINT "(R3T X R4T) (R3T X R5T) =";P4,
4651 PRINT
4652 LET P5=P1*P3
4653 PRINT "(R3T X R4T) (R4T X R5T) =";P5,
4654 PRINT
4655 LET P6=P2*P3
4656 PRINT "(R3T X R5T) (R4T X R5T) =";P6,
4657 PRINT
4658 LET P7=P1*P2*P3
4659 PRINT "(R3T X R4T) (R3T X R5T) (R4T X R5T) =";P7,
4660 PRINT
4661 PRINT
4662 GOTO 237
4735 PRINT "NET X=";N[Q];"S. +Y AXIS + D. R QI[4735-1]"
4736 GOTO 2080
4835 PRINT "NET X=";N[Q];"S. L+ QII D. QI[4835]"
4836 GOTO 2080
4935 PRINT "NET X=";N[Q];"D & S Y AXIS D+[4935]"
4936 GOTO 4937
4937 IF J[Q]= 0 GOTO 4942
4938 LET J[Q]= 0
4939 LET L=-(H[Q])
4940 LET Z=N[Q]
4941 GOTO 3638
4942 LET J[Q]=90
4943 LET L=N[Q]
4944 LET Z=H[Q]
4945 GOTO 3638
4956 GOTO 5036
4995 LET Q= 0
4996 DIM X[2]
4997 DIM Y[2]
4998 DIM A[2]
4999 DIM O[2]
5000 DIM N[2]
5001 DIM H[2]
5002 DIM J[2]
5003 LET R6= 0
5004 LET R7= 0
5005 LET R8= 0
5006 GOTO 5026
5008 PRINT "DET. X, Y?"
5009 INPUT X[Q],Y[Q]
5010 PRINT
5011 PRINT "SRCE X, Y?"
5012 INPUT A[Q],O[Q]
5013 PRINT
5014 PRINT "V=0 OR H=90?"
5015 INPUT V
5016 PRINT
5017 PRINT "DET. INCR. ?"
5018 INPUT D

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6036 GOTO 5336
6135 PRINT "NET X=";N[Q];"SRCE. R DWNFLD ALL QI[6135]"
6136 GOTO 5035
6335 PRINT "NET X=";N[Q];"SRCE L DWNFLD ALLQIII[6335]"
6336 GOTO 7236
6435 PRINT "NET X=";N[Q];"SRCE AL DWNFLD ALL QIII[6435]"
6436 GOTO 4936
6535 PRINT "NET X=";N[Q];"SRCE. R DWNFLD ALL QIII[6535]"
6536 GOTO 5036
6635 PRINT "NET X=";N[Q];"S. QIII D. -Y AXIS + [6635]"
6636 GOTO 7236
6735 PRINT "NET X=";N[Q];"D. -Y AXIS + S QIV[6735]"
6736 GOTO 5036
6835 PRINT "NET X=";N[Q];" S. L QIII D. + QIV[6835]"
6836 GOTO 7236
6935 PRINT "NET X=";N[Q];"S & D Y AXIS D. +[6935]"
6936 GOTO 4936
7035 PRINT "NET X=";N[Q];"SRCE. -Y AXIS DET L+ Q III [7035]"
7036 GOTO 5036
7135 PRINT "NET X=";N[Q];"SRCE R DWNFLD QIV DET QIII[7135]"
7136 GOTO 5036
7235 PRINT "NET X=";N[Q];"SRCE. -Y AXIS DET. R+ QIV[7235]"
7236 GOTO 7237
7237 IF J[Q]= 0 GOTO 3636
7238 LET J[Q]= 0
7239 LET L=-(H[Q])
7240 LET Z=N[Q]
7241 GOTO 3638
7335 PRINT "NET X=";N[Q];"S. L DWNFLD ALL QIV[7335]"
7336 GOTO 7236
7435 PRINT "NET X=";N[Q];" S. AL DWNFLD ALL QIV[7435]"
7436 GOTO 4936
7535 PRINT "NET X=";N[Q];"S. R DWNFLD ALL QIV[7535]"
7536 GOTO 5036
7735 PRINT "NET X=";N[Q];"S. L+ QIII D. QII[7735]"
7736 GOTO 2079
7835 PRINT "NET X=";N[Q];"S. AL+ QIII D. QII[7835]"
7836 GOTO 3736
7935 PRINT "NET X=";N[Q];"S. R+ QIII D. QII[7935]"
7936 GOTO 4590
8035 PRINT "NET X=";N[Q];"SRCE. L+ QIII DET. Y AXIS[8035]"
8036 GOTO 2079
8135 PRINT "NET X=";N[Q];"SRCE. +R Q IV, DET Y AXIS[8135]"
8136 GOTO 4590
8235 PRINT "NET X=";N[Q];"SRCE L+ QIII DET QI[8235]"
8236 GOTO 2079
8335 PRINT "NET X=";N[Q];"DETECT. & SOURCE ON Y AXIS, SOURCE UPFIELD"

8336 GOTO 3736
8435 PRINT "NET X=";N[Q];"SRCE. Y AXIS+, DET L QII[8435]"
8436 GOTO 4590
8535 PRINT "NET X=";N[Q];"SRCE. R+ QIV DET QII[8535]"
8536 GOTO 4590
8635 PRINT "NET X=";N[Q];"S. Y AXIS D. R QI[8635]"
8636 GOTO 2079
8735 PRINT "NET X=";N[Q];"S. L+ QIV D. QI[8735]"
8736 GOTO 2079
8835 PRINT "NET X=";N[Q];"S. AL+ QIV D QI[8835]"
8836 GOTO 3736
8935 PRINT "NET X=";N[Q];"S. R+ QIV D QI[8935]"
8936 GOTO 4590

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9135 PRINT "NET X=";N[Q];"S. L: ALL QIII[9135]"
9136 GOTO 2079
9235 PRINT "NET X=";N[Q];"S. AL: ALL QIII[9235]"
9236 GOTO 3736
9335 PRINT "NET X=";N[Q];"S. R: ALL QIII[9335]"
9336 GOTO 4590
9435 PRINT "NET X=";N[Q];"SRCE. L: QIII DET Y AXIS[9435]"
9436 GOTO 2079
9535 PRINT "NET X=";N[Q];"S. R: D. Y AXIS[9535]"
9536 GOTO 4590
9635 PRINT "NET X=";N[Q];"S. L: QIII D. QIV[9635]"
9636 GOTO 2079
9735 PRINT "NET X=";N[Q];"S. : ALL Y AXIS[9735]"
9736 GOTO 3736
9835 PRINT "NET X=";N[Q];"S. : Y AXIS D. QIII[9835]"
9836 GOTO 4590
9935 PRINT "NET X=";N[Q];"S. R: QIV D. QII[9935]"
9936 GOTO 4590
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