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TITLE: CALIBRATION OF THE SUDBURY NEUTRINO OBSERVATORY PHOTOMULTIPLIERS THROUGH THE NEUTRAL-CURRENT DETECTOR ARRAY

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CALIBRATION OF THE SNO PMTs THROUGH THE NCD ARRAY

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ABSTRACT

The addition of the neutral current detectors to the Sudbury Neutrino Observatory may inhibit the calibration of the photo multiplier tubes which constitute the charged current detector apparatus. It has been shown that the photo multiplier tube array can still be calibrated with relative ease with the neutral current detectors in place.

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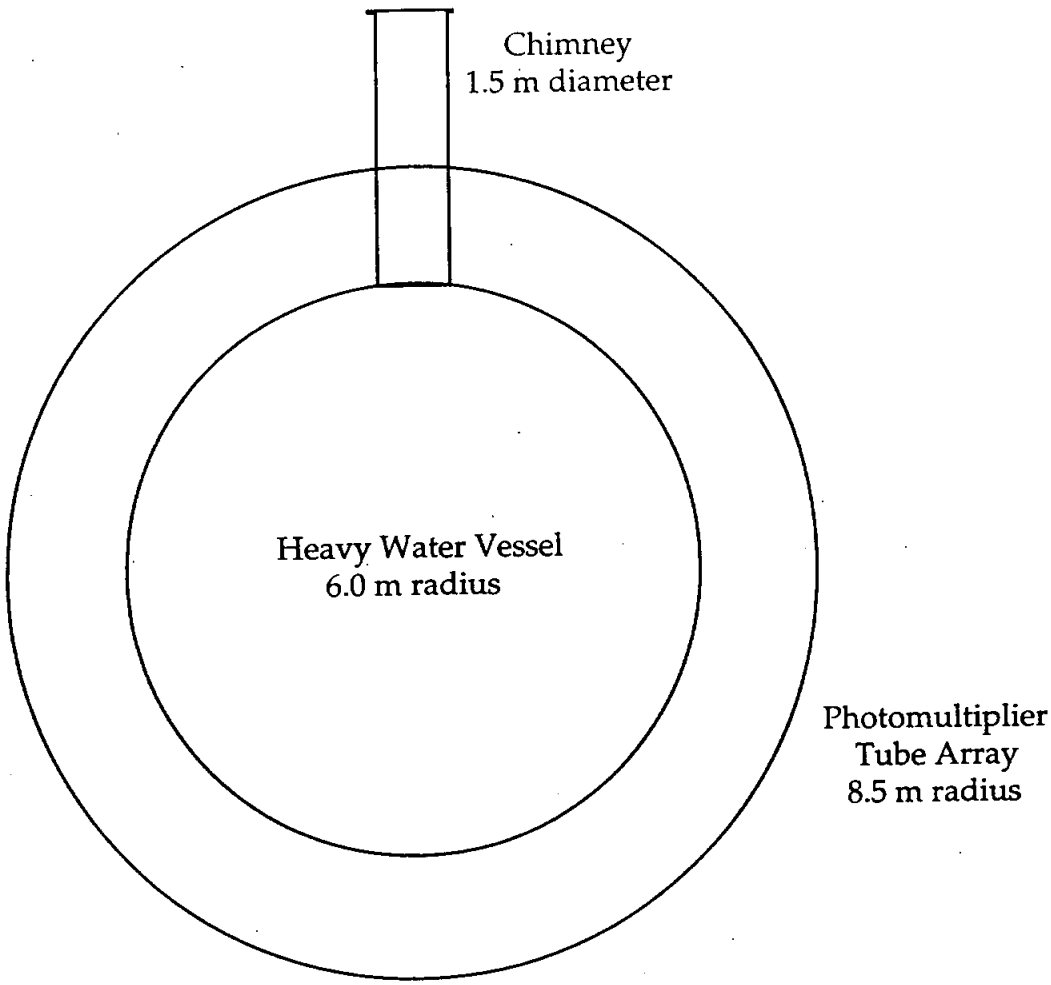
INTRODUCTION

The layout of the Sudbury Neutrino Observatory (SNO) consists of a large spherical vessel (radius 6 meters) containing ultra pure heavy water--the neutrino interaction medium. Situated on top of the D_2O vessel is a 1.5-meter-diameter chimney through which everything entering the vessel must pass. In order to detect the charged-current events, a spherical array (radius 8.5 meters) of photomultiplier tubes will enclose the D_2O vessel.

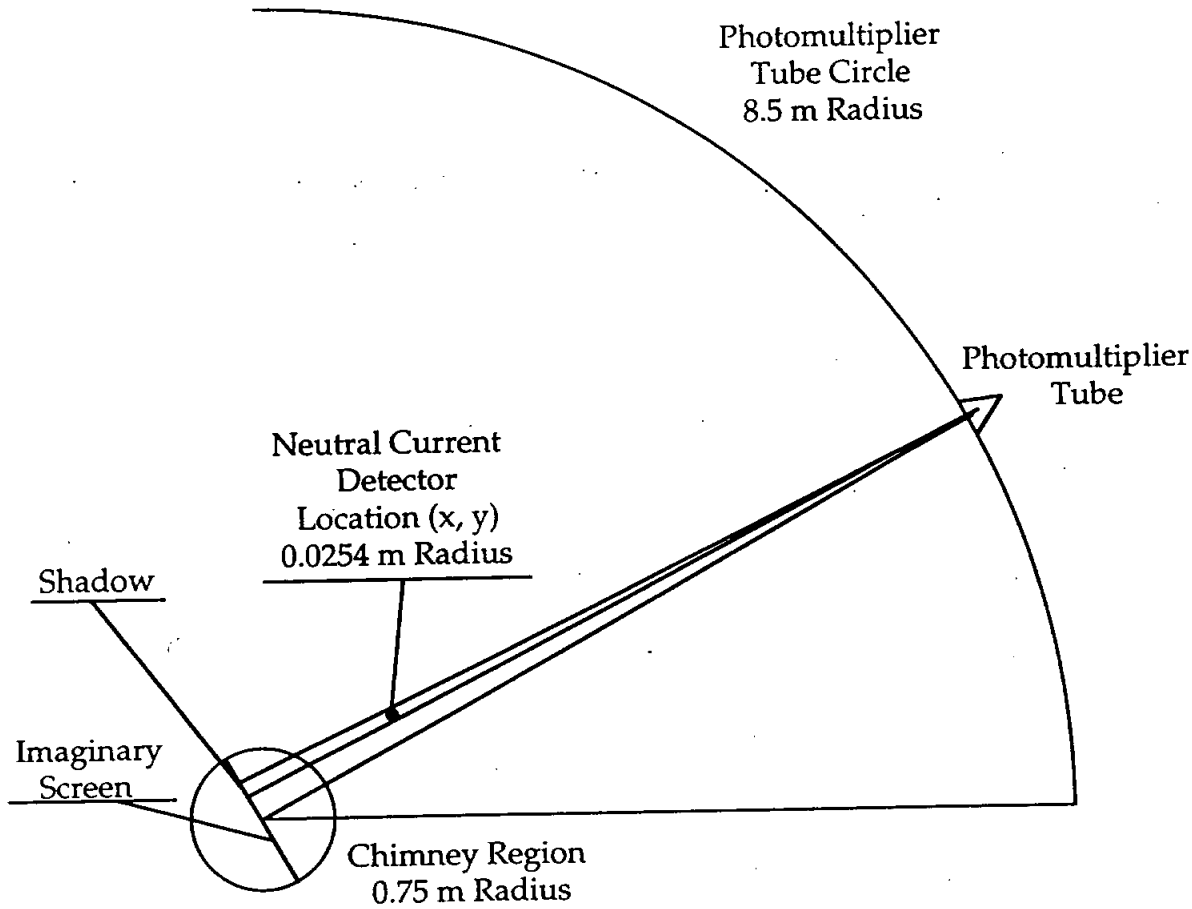


In addition, proportional counters will be used to detect the neutral-current events. These so called neutral-current detectors (NCD's) consist of long, thin Nickel tubes positioned vertically inside of the D_2O vessel and organized in a horizontal array. The addition of the neutral current detectors to SNO poses several challenges in terms of being able to calibrate the entire photo multiplier tube array by simply lowering a calibration light source down the chimney. The

question is, will there be any point on the PMT array that cannot receive direct light from some point within the chimney region?

Since the NCD's are oriented vertically, the problem degenerated to two dimensions. All of the calculations took place on the equatorial plane of the D_2O vessel. Each NCD had rectangular coordinates with respect to the center of the vessel.

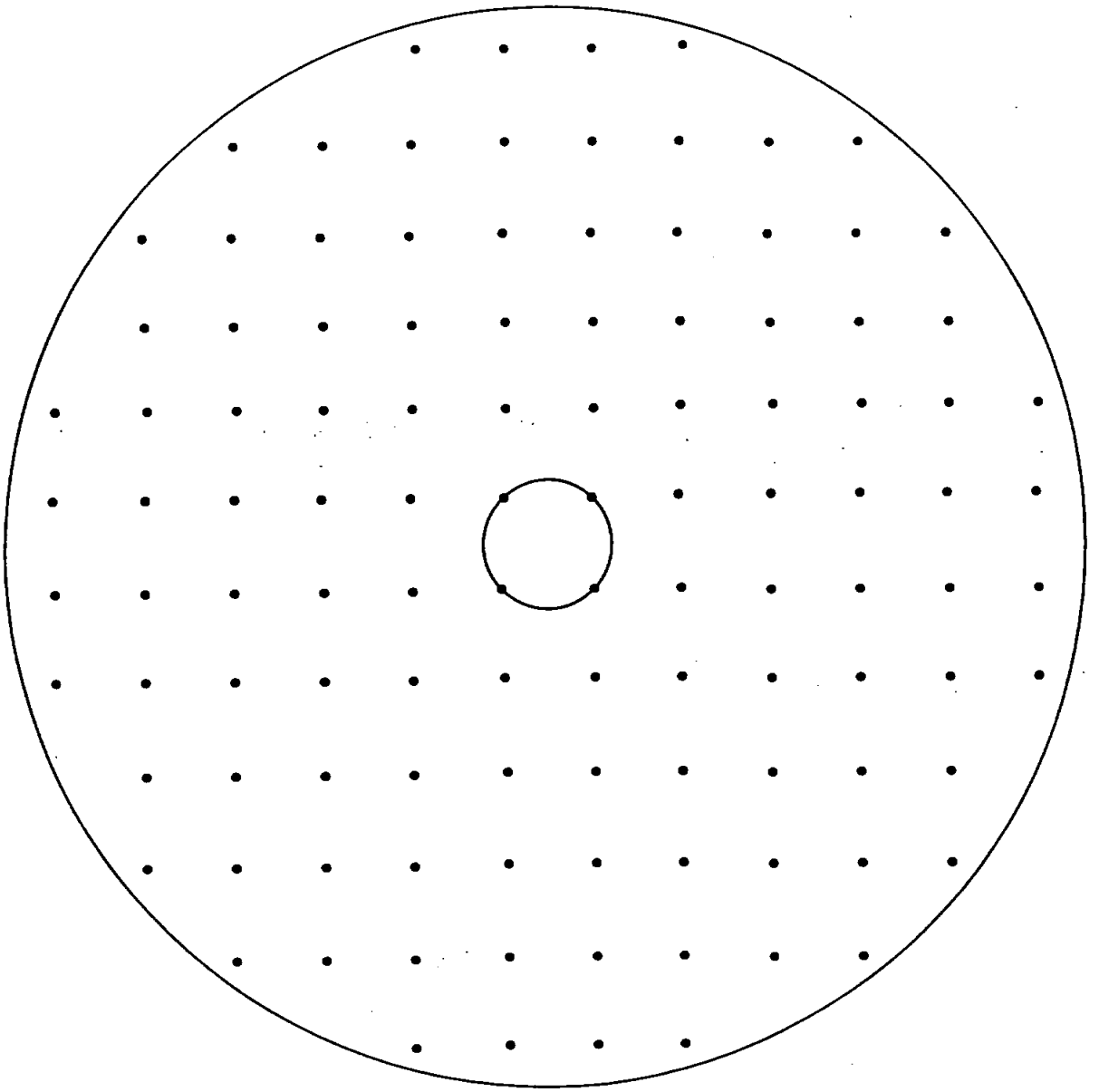
Initially, a "proof of concept" algorithm was developed which in essence determined that it was indeed possible to see the entire equator of the PMT array, or so called PMT circle, from somewhere within the chimney region. In the algorithm, the NCD's were projected from the point in question on the PMT circle onto an imaginary screen stretched across the diameter of the chimney region. The algorithm then determined that there was at least a small part of the screen which was not blocked by a NCD. To change points in question on the PMT circle, the algorithm rotated the PMT circle (relative to the NCD array) through an arbitrarily small angle.



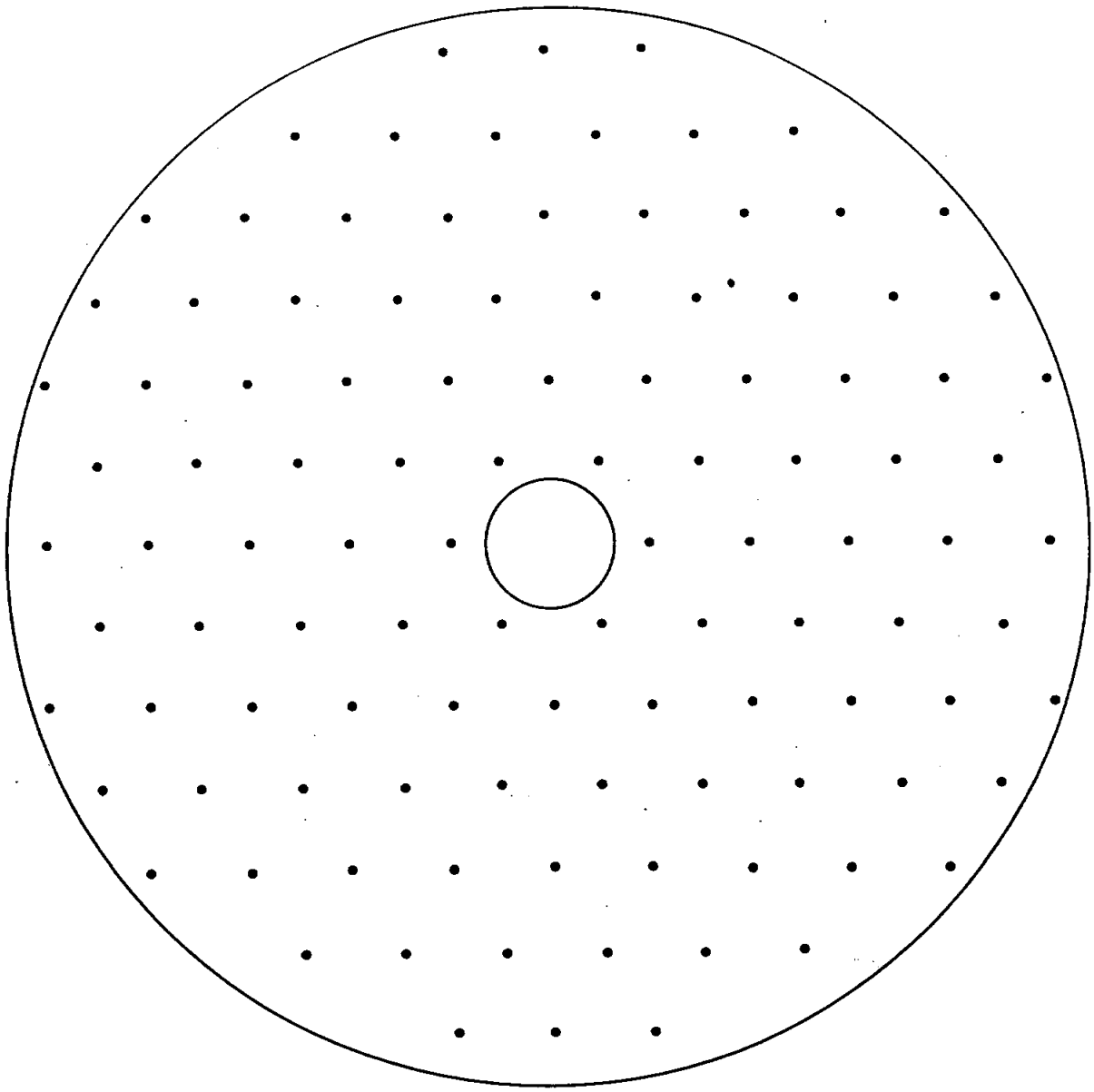
NEUTRAL CURRENT DETECTOR ARRAYS

There are two neutral-current detector arrays under consideration: a square array and a hexagonal array.

	SQUARE ARRAY	HEX ARRAY
SPACING	1.00 meter	1.07 meter
NUMBER OF TUBES	112 tubes	108 tubes
RADIUS OF NCD TUBES	2.54 cm	2.54 cm

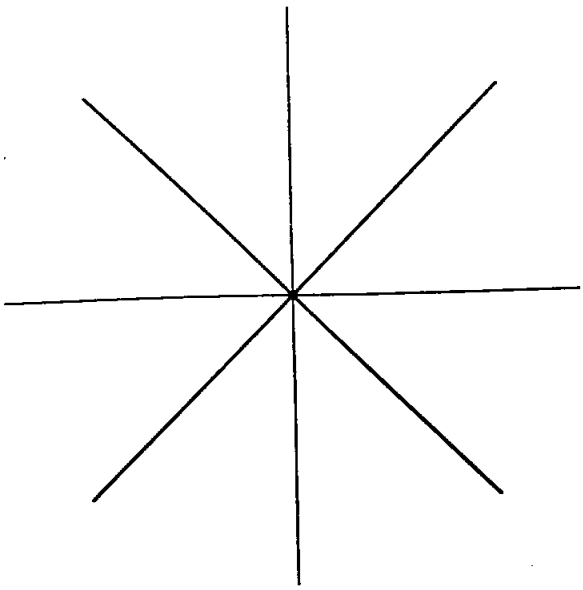


PLAN VIEW OF SQUARE ARRAY

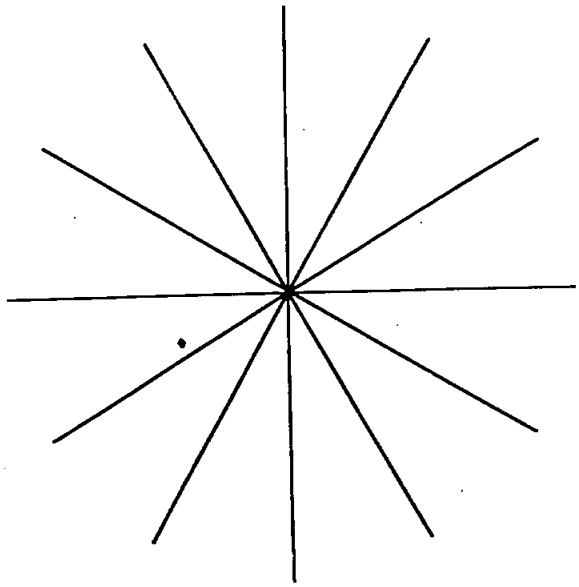


PLAN VIEW OF HEX ARRAY

Each array has several axes of symmetry associated with it. All calculations were done for the entire array, instead of for one quadrant, so as to be able to verify expected symmetries, i.e. four-fold symmetry for the square array and six-fold symmetry for the hex array. These symmetries were used to determine whether or not the algorithms were doing what they were supposed to. In theory, given symmetrical inputs, the outputs should be similarly symmetrical.



Axes of Symmetry for
Square Array



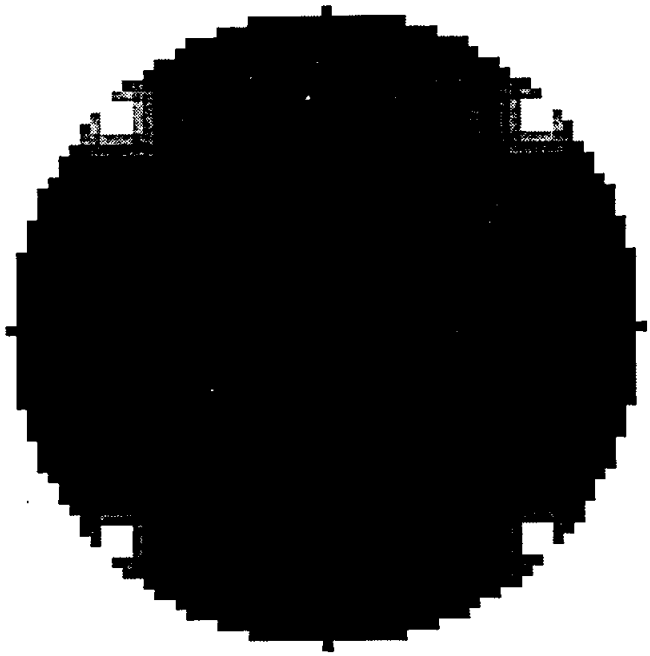
Axes of Symmetry for
Hex Array

DETERMINING CALIBRATION SOURCE LOCATIONS

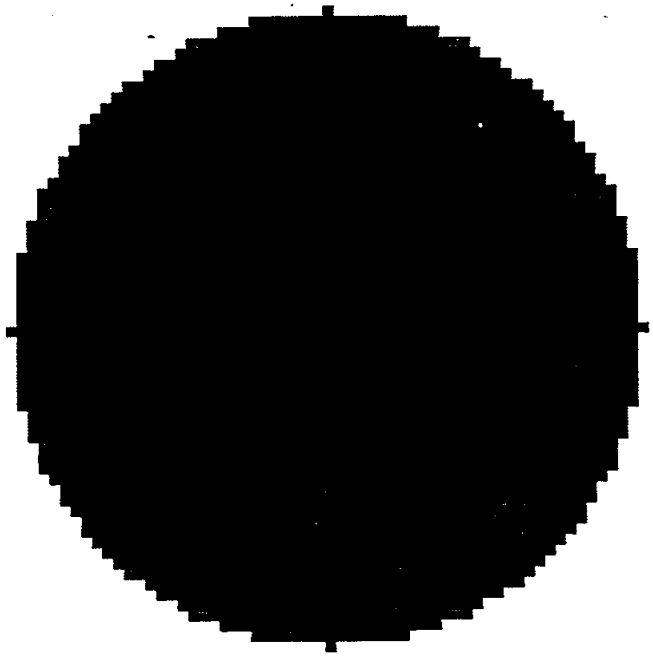
In order to find the best places in the chimney region from which to calibrate the entire PMT array, a grid was imposed on the chimney region. For a given point on the grid, each angle around the circle, separated by a selected small angular increment, was checked to see if any portion of a NCD blocked that angle. All of the angles which were not blocked were counted up. The total became the calibration efficiency for that particular grid point. For example, if angles at every 0.36 degrees were checked, then there would be 1,000 angles around the circle. If at some given grid point, only 700 of those angles had a clear line of sight, then the calibration efficiency for that grid point would be 700.

The grid squares had 2.5 cm spacing. For the square array, the angular increment was 0.36 degrees, giving 1,000 angles around the circle. For the hex array, the angular increment was 0.30 degrees, giving 1,200 angles around the circle. The angular increment for the hex array was changed from 0.36 to 0.30 degrees at the last minute to ensure that the number of sampled angles around the circle was evenly divisible by the number of axes of symmetry.

An image showing the efficiencies of every point on the grid was created for each NCD array in order to map out the best places for the calibration source. The dark regions on each image indicate the grid points with the highest efficiencies.



Square Array



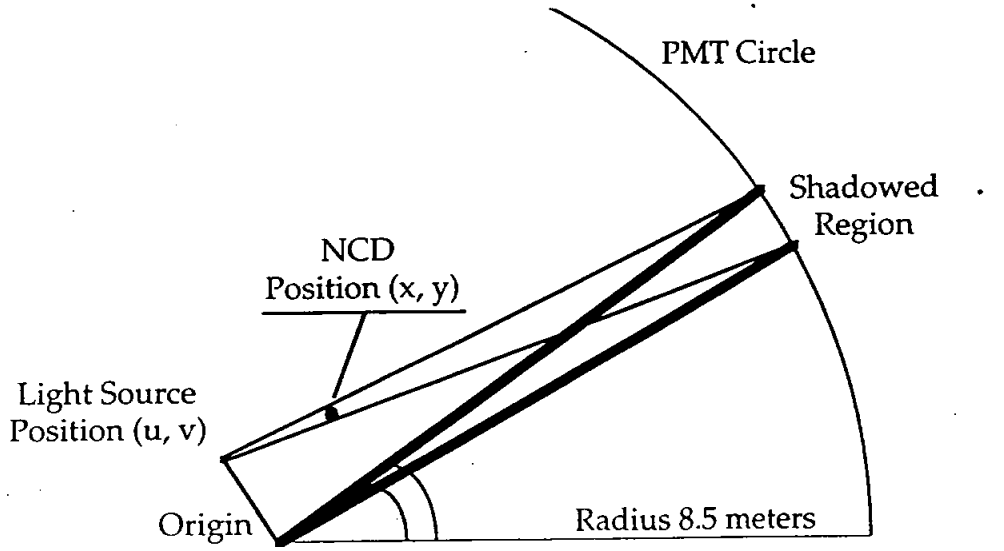
Hex Array

The images clearly show the expected symmetries. The best calibration locations can also be easily seen. The following table shows the coordinates in meters with respect to the center of the vessel of the highest efficiency grid points.

SQUARE ARRAY	HEX ARRAY
(0.5, 0.0)	(0.0, 0.0)
(0.0, 0.5)	(0.55, 0.0)
(-0.5, 0.0)	(0.275, 0.476314)
(0.0, -0.5)	(-0.275, 0.476314)
	(-0.55, 0.0)
	(-0.275, -0.476314)
	(0.275, -0.476314)

FINDING THE MINIMUM NUMBER OF SOURCE LOCATIONS

Once the locations in the chimney region with the highest calibration efficiencies were known, it became necessary to determine whether the entire PMT array could be calibrated by placing a calibration source at only those locations, and given that, to then determine the minimum number of calibration locations which would be required. Given several calibration source locations (u, v) in the grid, for each location the algorithm calculated all of the angular regions which were blocked by a NCD, and then converted the boundaries of those regions to angles with respect to the center of the vessel, or origin. This way, the shadowed regions associated with one location could be compared with the shadowed regions of another.

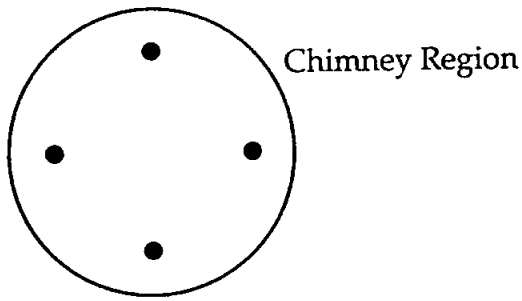


The algorithm then sampled angles around the circle, separated by an arbitrarily small angular increment and determined how many of the given source locations failed to cast light at each angular position in question. If this number was less than the number of given source locations, then the angular position in question did receive direct light from at least one of the source locations.

In the determination, an angular increment of 0.1 degrees was used. This angular spread represents 1.5 cm on the PMT circle, or approximately 7% of the diameter of one of the PMT's. The histograms shown below plot the number of hits for each angular position around the circle.

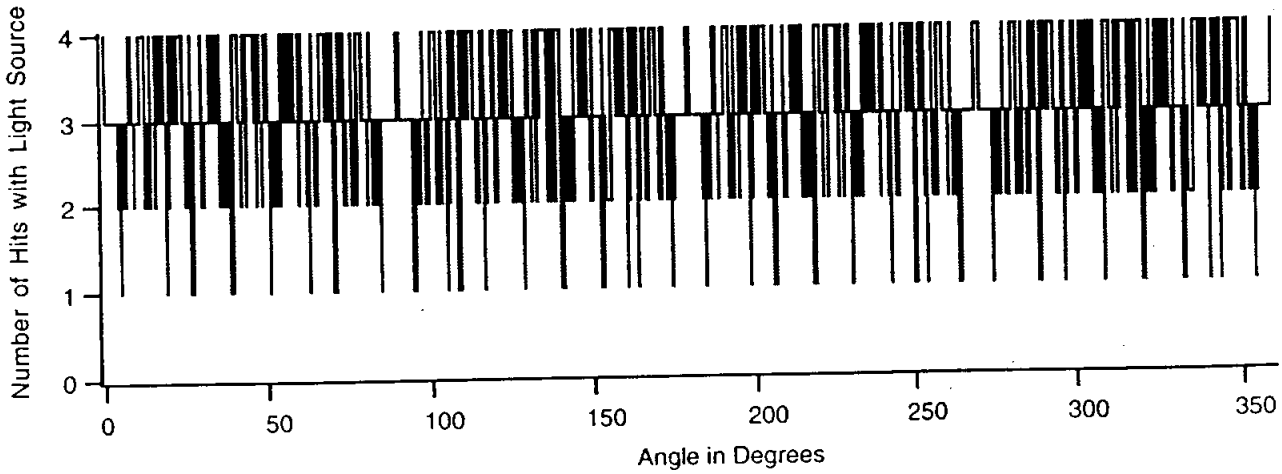
Calibration Source Locations Used In Square Array:

(0.5, 0.0)
(0.0, 0.5)
(-0.5, 0.0)
(0.0, -0.5)



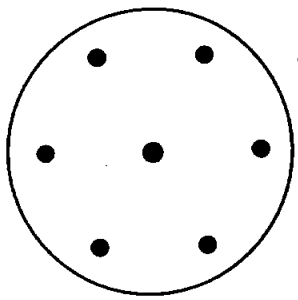
CALIBRATION SOURCE LOCATIONS

Square Array Histogram
0.1° Angular Increment



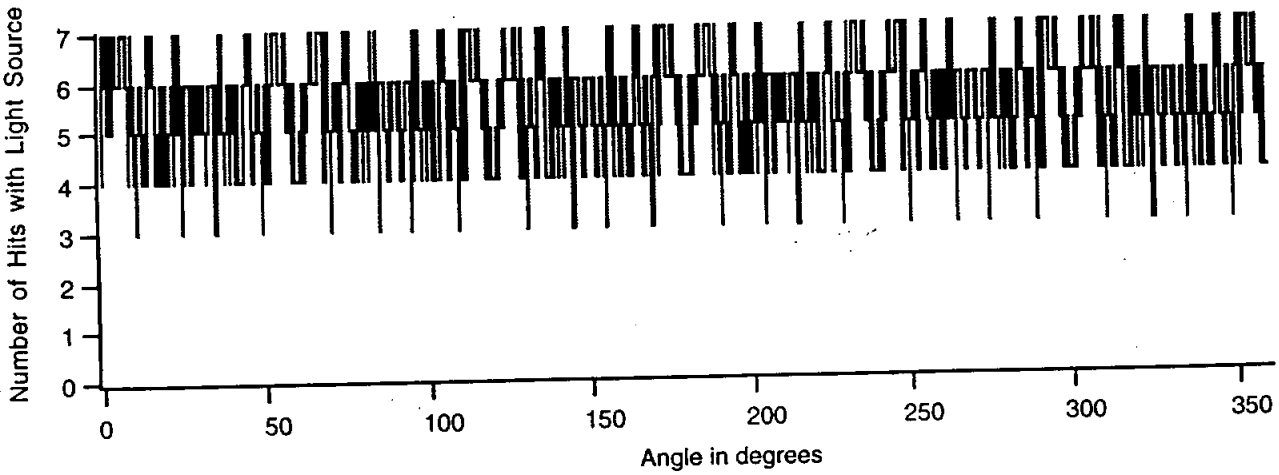
Calibration Source Locations Used In Hex Array:

(0.0, 0.0)
(0.55, 0.0)
(0.275, 0.476314)
(-0.275, 0.476314)
(-0.55, 0.0)
(-0.275, -0.476314)
(0.275, -0.476314)



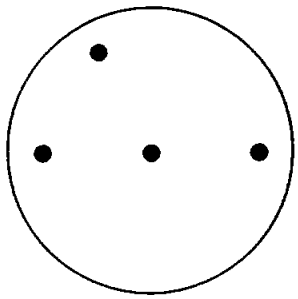
CALIBRATION SOURCE LOCATIONS

Hex Array Histogram
0.1° Angular Increment

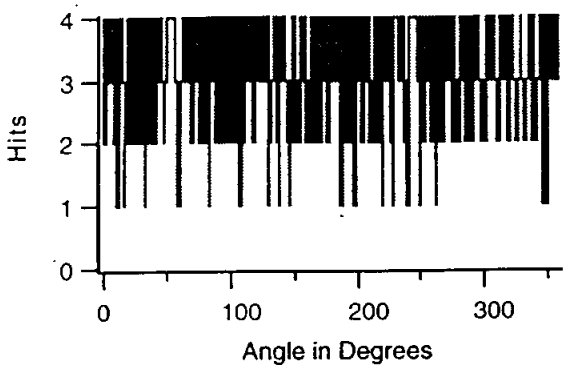


The set of source locations for each detector array possessed the same symmetries as its corresponding array. As expected, the anticipated symmetries are visible in these histograms.

The Hex array, however, can be calibrated with only four source locations, but not just any four. Of the best locations, any arrangement of points with three points on an axis, and another off axis point can calibrate the entire PMT array.

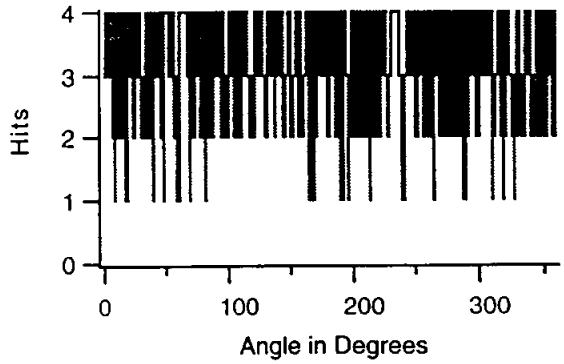


General Layout of
Source Locations



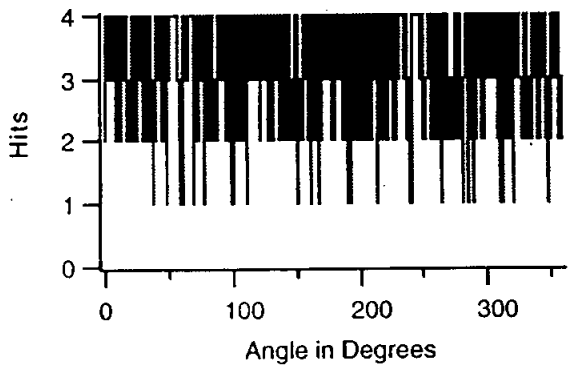
Locations Used in Histogram:

(-0.275, -0.476314)
(0.0, 0.0)
(0.275, 0.476314)
(0.275, -0.476314)



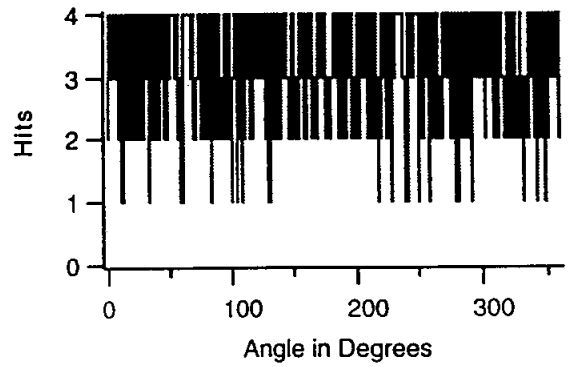
Locations Used in Histogram:

(-0.275, -0.476314)
(0.0, 0.0)
(0.275, 0.476314)
(-0.275, 0.476314)



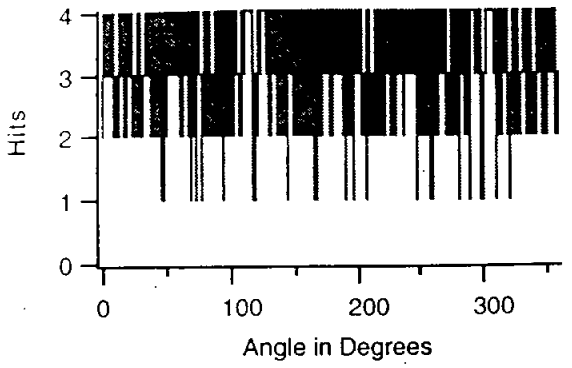
Locations Used in Histogram:

(-0.275, -0.476314)
(0.0, 0.0)
(0.275, 0.476314)
(0.55, 0.0)



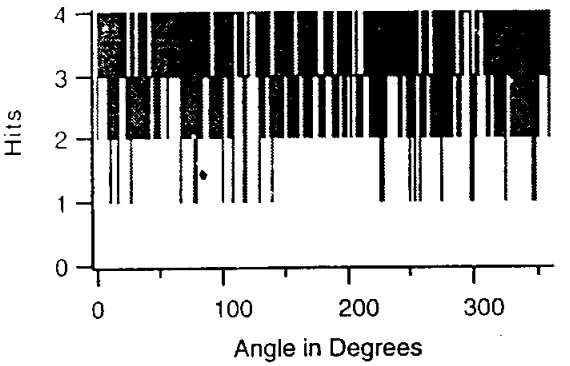
Locations Used in Histogram:

(-0.275, -0.476314)
(0.0, 0.0)
(0.275, 0.476314)
(-0.55, 0.0)



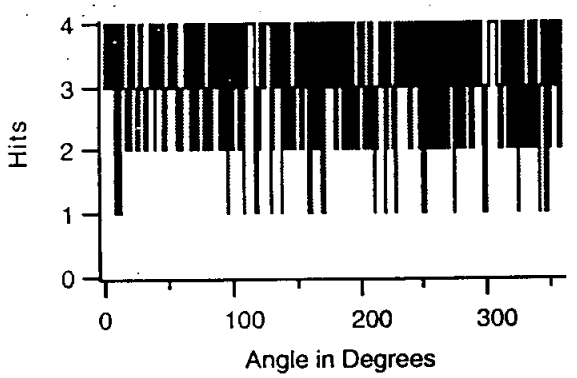
Locations Used in Histogram:

(-0.275, 0.476314)
(0.0, 0.0)
(0.275, -0.476314)
(0.55, 0.0)



Locations Used in Histogram:

(-0.275, 0.476314)
(0.0, 0.0)
(0.275, -0.476314)
(-0.55, 0.0)



Locations Used in Histogram:

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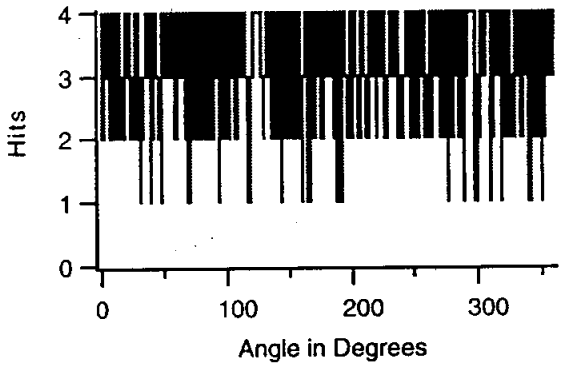
(0.0, 0.0)
(0.275, -0.476314)
(0275, 0.476314)



Locations Used in Histogram:

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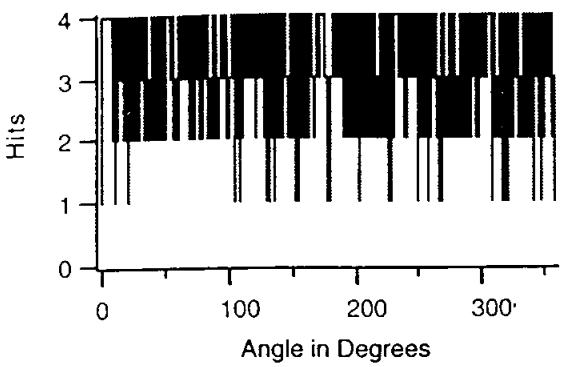
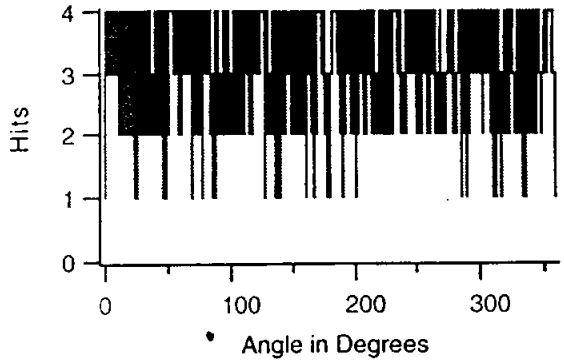
(0.0, 0.0)
(0.275, -0.476314)
(-0.275, -0.476314)



Locations Used in Histogram:

(0.55, 0.0)
(0.0, 0.0)
(-0.55, 0.0)
(0275, 0.476314)



Locations Used in Histogram:

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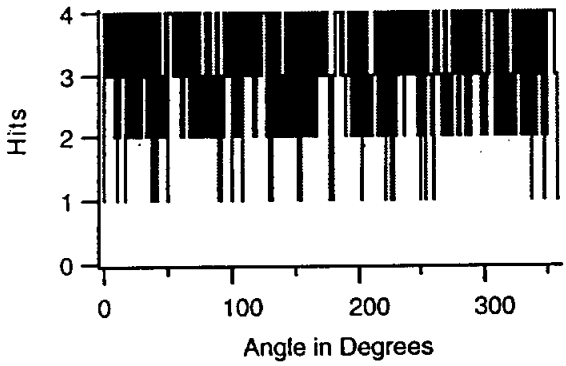

Locations Used in Histogram:

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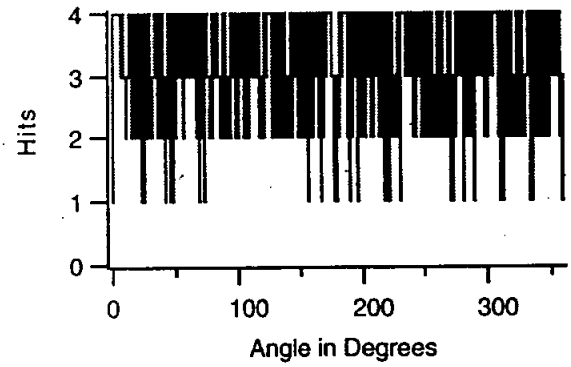
(-0.55, 0.0)
(0275, -0.476314)



Locations Used in Histogram:

(0.55, 0.0)
(0.0, 0.0)
(-0.55, 0.0)
(-0.275, 0.476314)

CONCLUSIONS

For both the hex array and the square array, four different calibration source locations within the chimney region will allow the entire PMT array to be calibrated. In the square array, these locations are obvious. In the hex array, however, the four locations must be selected out of the seven best locations in a particular way.