BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.

Upton, New York 11973

Department of Nuclear Energy
(516) 345-7690

November 30, 1979

Mr. Robert L. Ferguson
Plant Systems Branch
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

RE: Evaluation of NUTECH's In Situ Test Method - NUTECH report SSP-01-001, October 3, 1979 "Smoke Simulation Prototype Test Conducted at Yankee Rowe Nuclear Plant."

Dear Bob:

In compliance with your request by letter dated November 7, 1979 the following is a composite evaluation, prepared with the collaboration of I. Asp, J. Klevan, and I. Pinkel, of the NUTECH test method for smoke detector siting. To some extent, the comments herein, re-emphasize our preliminary appraisal, by letters dated September 21 and October 17, 1979 to C. Heit, of the use of tracer gas for smoke detector siting. Although Mr. Pinkel did not participate directly in the NUTECH test at Yankee Rowe as did I. Asp, J. Klevan, and myself, he did attend the June 20, 1979 pretest conference at the Nuclear Regulatory Commission (NRC) and did review the cited document. His preliminary views on the subject matter are contained in his October 30, 1979 letter to me; a copy of which had been forwarded to you.

At the outset, I must categorically state that I find the use of tracer gas, such as sulfur hexafluoride (SF_6) in conjunction with electron-capture gas chromatography an acceptable technique for assessing the convective flow patterns within (or around) complex geometries. I have culled the open literature, especially in the fields of meteorology, atmospheric environment, and industrial aerodynamics and found the tracer gas technique to be used for

1. experimentally characterizing ventilation systems in buildings,
2. for probing the air flow within the wake downwind of buildings, and
3. for study of pollutant transport and dispersion from sources ranging from smoke stakes to large urban areas.

Thus it certainly appears feasible that the tracer gas technique can be used for the study of smoke movement. Understandably, of course, the experimental program requires more care in execution than had heretofore been exercised when smoke movement is dominated by internal flow patterns within an enclosed space (such as the switch gear room at Yankee Rowe) which also contains the source.

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However, to fully satisfy the requirement set forth in Section 4.2 of a NRC letter to Yankee Atomic Electric Company (YAEC), dated March 15, 1979, namely tnat

> "In situ tests will be conducted with a suitable smoke generation device to verify that products of combustion from a fire will be promptly detected by installed smoke detectors and that ventilation air flow patterns in the area does not significantly reduce or prevent detection response. These tests are dependent upon a development of a suitable smoke generating device."

is beyond present state-of-the-art technology in smoke detector siting and response criteria. Implied in the aforenoted quote are the following requirements for in situ tests for siting smoke detectors:

1. Development of a suitable tracer which would spread in the manner of smoke generated from an incipiant fire,
2. Means for detecting simulated (tracer) smoke concentrations,
3. Assurance that air flow patterns do not significantly reduce or prevent detection response, and
4. Verification that products of combustion will be promptly detected by installed smoke detectors

of which we will show that the NUTECH test are a partial response of this four part requirement.

Thus, before proceeding with an evaluation of the NUTECH approach some basic ground work in the properties of smoke, smoke detector design and siting must be first established. The following draws heavily on the continuing research performed at the National Bureau of Standards (NBS) and by their contractors. Currently, a five year study program in the area of fire detection and smoke control is underway at NBS, which according to Dr. Fredric B. Clarke, director of the Center for Fire Research, contains the following milestones, viz.,

Fiscal Year	Milestones
1979	Recommend placement guidelines for detectors in single/multifamily homes and mobile homes.
1980	Recommend second-generation smoke detector test concept: either full scale or using artificial aerosols.
1981	Publish decision manual for use with available smoke control equipment.
1982	Submit second generation smoke detector tests to NFPA.
1983	Publish results of correlations between physical/chemical character of smoke aerosols and fire/fuel parameters.

In his August 1979 presentation on NBS's long range plan he indicates a need for this research because "at present the smoke detector test methods ...constitute go/no go tests with a single aerosol system" and that there are "significant differences in both particle size and optical properties among the many kinds of smoke present in fires." Existing test methods "lack the sophistication necessary to differentiate among the various smoke detection principles, and even the differences in sensitivity for variations in smoke characteristics among detectors employing the same principles."

In particular, the Center's approach to the development of smoke control technology includes a number of discrete but interrelated efforts. Two "cold smoke" technique's, pressure mapping and SF_6 tracer gas, are currently being used to map the air movement in a variety of buildings. It is essentially this latter technology that NUTECH has extended in their selection of optimum smoke detector locations. The selection criteria, described in the cited reference as "identifying the smoke detector location that would first see the smoke from a fire in the test location" cannot account for the correspondence between the threshold response of a given detector wth the physical/chemical character of smoke aerosols and the fire/fuel parameters, which is crucial if one wishes to "verify that products of combustion from a fire would be promptly detected by installed smoke detectors." Predictably, Phase 2 of NUTECH's overall test plan which would be in-place testing of each smoke detector head with a portable aerosol generating device to simulate smoke would attempt to verify the alarm setpoint, but further research as indicated by the aforenoted NBS milestones is required.

However, depending upon the actual material burning and the condition in which it burns (smoldering or flaming), the actual smoke aerosol can have a wide range of properties. From a detection point of view the properties of interest are number and mass concentration, optical density, and size distribution. In addition, one must keep in mind that an aerosol particle size distribution is dynamic, varying with time and distance from the generation source. The particle diameter will tend to increase due to coagulation effects which are related principally to time and concentration. Also the particle size distribution being generated can change as a function of combustion temperature, material, its density and moisture content, and other factors.

To see the relative importance of these factors to detector response consider for the moment the operation of ionization detectors (a substantial fraction of smoke detectors used within reactor facilities are of the ionization type). The chamber within an ionization detector consists of a source of ionizing radiation positioned between two electrodes across which an electric potential is maintained. Positive ions are created by removing electrons from gas molecules passing across the path; the low energy electron released rapidly attaches to a neutral gas molecule which then becomes a negative ion. These ions are then drawn to the respective electrodes, giving up their charge and thereby maintaining a small current flow through the airspace between the electrodes.

Normally, the ion velocities are high enough and the convective flow rate low enough so that most ions reach their respective electrodes. When smoke particles enter the chamber, these particles capture ions, reducing their transfer velocity by several orders of magnitude due to the increased mass of the particle-ion pair. This reduced velocity allows the pair to be carried from the chamber before reaching the electrode, reducing the charge transfer and consequently the chamber current which is subsequently used to trigger the alarm. This brief description indicates three factors which are important in threshold response viz smoke particle diameter, concentration and convective velocities.

NBS Technical Note 973 entitled "Smoke Detector Design and Smoke Properties" authored by R.W. Bukowski and G.W. Mulholland indicates that for low concentrations of monodisperse smoke aerosol the relative chamber signal is directly proportional to the number of particles and particle diameter, i.e.,

$$S \sim Nd_p$$

where $S \equiv$ relative chamber signal $= \Delta I/I_o$
$N \equiv$ number of particles of size d_p
$d_p \equiv$ particle diameter

with the proportionality constant a function of chamber design. They indicate also that the number concentration of liquid aerosol droplets or aerosols composed of solid nuclei with condensed liquid exteriors of a fixed mass concentration is inversely proportional to the diameter cubed. Thus, if the aerosol diameter doubles, say due to aging effects, the number concentration would be reduced by 1/8 so that the overall effect would be the reduction of the relative chamber signal by a factor of 4. This observation then lends some credance in selecting optimum ionization smoke detector sites as those which first "see the smoke" but it presupposes that the generating source has already created the requisite number concentration of particles of a size sufficient to trigger the detector. It may be conceivable that the particle size generated is too small for detector response and that some aging is required necessitating a detector site "down stream" of that which initially "sees the smoke."

The other factor, i.e., convective flow velocity, also has pronounced effects on chamber signal. The effect of high air velocities is to convect the charged ions from the chamber before they can reach the electrodes and give up their charge. Thus under this condition the charge transfer would be reduced, decreasing the chamber current and moving it toward alarm. High velocities would have the effect of enhancing the sensitivity but can also cause a false alarm if the velocity is sufficient to remove enough ions. Again, first "seeing the smoke," which in the context of a room dominated by the convective patterns produced by the HVAC system (as is the case in the switch gear room at Yankee Rowe) is tantamount to areas of "high" flow velocities, may be a criteria for detector siting but one must still factor into this the possible increase in occurrences in false alarms. An optimal location may be downstream of this location where smoke velocities have been reduced via mixing with stagnant or lower velocity ambients.

Research on the effects of particle size and size distribution on smoke detector sensitivity is continuing at NBS in conjunction with the excellent capabilities at the University of Minnesota for the measurement and generation of aerosols. Figures 1, 2, and 3 taken directly from Bukowski and Mulholland's report on smoke detectors show to some extent the effects of particle size on detector sensitivity (Figure 1) and size distribution as a function of material burned (Figures 2 and 3). From Figure 1 the ionization

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detector can be correlated with particle diameter using a linear fit to a log-log plot. This indicates a power law relationship between detector sensitivity and particle size with the empirical relationship being (given by Bukowski and Mulholland)

$$S = 6.7\,\overline{D}_g^{1.1}$$

with $\overline{D}_g$ the geometric mean diameter defined as

$$\log \overline{D}_g = \sum_{i=1}^{n} \Delta N_i \log D_i / N$$

where N represents the total number of particles and n represents the number of size classes. Figures 2 and 3 indicate that the geometric mean diameter is a function of the material burned and how it is consumed. The tracer gas test methodology cannot differentiate these effects, i.e., it cannot simulate the particle size and its distribution normally ascribed to smoldering and/or flaming forms of combustion.

With some basic ground work in current and future status of smoke detector design and research in smoke properties thus laid we are now in a position to evaluate, on general principles, the NUTECH test concept. First, we must reemphasize that the requirements stated by NRC for in situ tests exceed the potential of the method. If more is demanded than existing techniques or information can supply than a useful approach to detector siting, which could provide some benefits now, may have to be discarded. We conside that effective implementation of the tracer gas technique is a viable approach in determining the migration of smoke from which one can use as a guide to assess the relative merits of one site location as compared to another. It cannot be used directly to verify prompt detection or effects of convection velocities on detector threshold response. Research at NBS is continuing to assess the effects. Accordingly, it is recommended to the NRC that Section 4.2 of the NRC letter to YAEC be restated to cover what can be done at this time keeping in mind the research being undertaken at NBS. A suggested rewrite is the following:

> In areas where probable smoke movement from realistic incipiant fires cannot be determined directly, tests should be conducted with a suitable gas tracer for smoke migration. Deterministic measurements of tracer gas concentration with time, together with the type of smoke detectors (ionization or light scattering) considered (or installed) the type of fire considered (flaming or smoldering) and the type of material likely to burn in a given area should be used as a guide to assess the advantages of one site-detector location relative to another. Data in the form of diagrams and photographs shall show room size and shape, location of major room objects, and all elements that govern air circulation.

However, notwithstanding possible changes in the NRC guidelines for smoke detector siting, examination of the actual tests results performed by NUTECH at the Yankee Rowe facility as reported in the cited reference and conclusions derived therefrom have to be clarified further. Indeed, they have demonstrated that SF_6 does spread with the air movement and that its concentration can be measured. Likewise, since the movement of smoke from incipient or small fires to other locations in the room is likely to be governed by the normal air movement and less by the buoyancy of smoke, one accepts the movement of SF_6 in these tests as being a useful duplication of smoke movement. In fact, although smoke aerosols encompass a broad size range from on the order of 0.005 micrometers for flaming fires (propane torch) to as large as 5 micrometers for smoldering fires (urethane foam), the particulate diameters are sufficiently small for one to assume that the ratio of particle diffusivity to gas eddy diffusivity is unity. Hence the tracer gas should diffuse like the aerosol. However, for flaming fires or fires (smoldering or flaming) located within "dead-air" regions of the room, true simulation of smoke movement using a tracer gas does necessitate closer simulation of the imposed buoyant flux. There are also other considerations such as:

1. Their conclusions as to the overall movement of air within the test room and the results of their tests are, in some instances, contradictory.

2. They have not fully explained the rationale leading to their various smoke detector location patterns.

3. Their normalization procedure for data presentation, coupled with the fact that the SF_6 source flow rate had not been constant, makes comparisons between tests rather difficult.

4. In some instances the composite data that is presented is inconsistant with the tabulated data.

5. Their criteria of identifying smoke detector locations as those regions within the test room that "would first see the smoke" (they really mean tracer gas) still must be proven.

6. The overlaid "smoke cloud" patterns are arbitrary and in some cases inconsistant.

These factors are now elaborated further. Possible suggestions for improvement are discussed later.

For the five detector location patterns depicted in Figure 4.2 of their report, I have ordered each of the eighteen grids on a smoke detector priority basis based upon the number of times a detector is requested at a particular location. For example, if at a particular grid location installation of a smoke detector is suggested in 4 out of the 5 recommended patterns, this location has an ordering of 8. This ordering is depicted in Figure 4 attached. Examining the raw data in concert together with the aforenoted figure, I cannot reconcile some of the recommended patterns NUTECH proposes. For example, the overall data shows that if the likelihood of a fire in each of the fire locations cited is equally probable and if optimum detector location is based upon, as NUTECH so stipulates, those locations which would "first see the smoke" then why do grid points B1 and C6 have zero site priority? Why does grid point A5 have a lower site priority than grid point C5 when the raw data shows that the former location is more susceptible to SF_6 movement than the latter? I fully recognize that this is a matter of judgement but I recommend to NRC that NUTECH should expound in more detail the rationale leading to Figure 4.2 of the cited report.

NUTECH has shown that the overall gross convective flow patterns within the test room is generally in the counter clockwise direction with a "dead air" region in the lefthand side of the room. Simple observations and/or the use of less sophisticated equipment requiring less than nineteen individuals could also have determined this fact. However if, indeed, the lefthand side of the room is a stagnant region in which tracer gas is trapped within, then why do tests 3 and 5 with simulated fire locations at the extreme righthand side of the room show relatively high concentrations within the lefthand side of the room. Also, for test 6 with the fire located in grid B3, the concentration gradient is approximately equal in both upstream and downstream directions from the source. These observations contradict the general character of the reported counter clockwise movement resulting from the HVAC system. I would have suspected tracer gas buildup in the lefthand portion of the room from simulated fires within the righthand portion to be much less than reported since the entrainment action would be only due to the shear forces acting across the dividing streamline which separates the general counter clockwise flow with the dead air region in the lefthand side of the room. Also, the inductive action of the HVAC intake duct situated in grid B3, as shown in the cited report on page B-3, would prevent flow from advecting into the lefthand portion of the room also negating SF_6 buildup in this area from a fire source located in grid B3. If the measurements are correct, I feel that a re-interpretation of the overall data is required and/or a finer grid resolution is needed.

There are also some inconsistancies between the tabulated data and the composite data presented in the figures entitled "Simulated Smoke Profile." Two noteworthy examples are the data presented in Figure 5.6 (Test 3) and Figure 5.10 (Test 5) and their associated tables. For Test 3, Figure 5.6 shows that the readings at sample station C4 are, for increasing time, 3, 11, 16, 18, 21 while the tabulated data (page D-3) for this location are 13.1, 16.4, 28.2, 23.6, and 32.8 respectively. Super position of this tabulated data onto the composite figure will distort the "smoke-cloud" pattern as originally depicted. For example, comparing grid location A4 with location C4, two sampling locations on opposite sides of the room, the data now indicates that the tracer gas concentration is approximately the same. This, I feel, contradicts the presumed general character of the counter clockwise flow in the room. Also, grid location C6 shows the greatest rise in concentration for this test and yet that station has a zero priority as a smoke detector site location.

For Test 5, the data as presented in grid location C6 (sampling sites C61, C62) do not compare with the tabulated data. Now, re-examining the data at sites A6, B6, C6, I cannot reconcile that if the overall convective pattern is counter clockwise why are grid points upstream of the source (located in A6) reading higher values than those just downstream. This would tend to indicate that the diffusional flux vector is greater than the convective flux vector. Mention had been made in the text of the report of a draft from the stairwell in A7 but this would tend to direct further the flow locally in the direction A6 to A1, i.e., in the global downstream direction. Possibly the exhaust port in grid C6-C7 could be a factor for this trend.

Data presented in Figure 5.4 (Test 2) are also in error when compared with the corresponding tabulated data. The errors are in grid B2 and according to

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the table on page D-2 should be (66, 45), (75. 100), (87, 91), (91, 46), (65, 50). This test indicated that the lefthand corner of the room is a relatively stagnant region; visual observations confirm this as well. However, the relatively low readings in location C2 and C3 have been attributed to the dilution effect due to the high air flow on top of the two battery rooms which are located within the area. This may or may not be true since the exhaust system operates as a flow sink and concentrations can be high in this region. I have plotted the data recorded at sample location C2 for Test 2, 3, 5, 6 (Figure 5 attached), which generally shows higher values for fire locations further away than that for Test 2. Examining this figure the question that naturally then arises is if dilution causes the lower readings for Test 2, then why not lower readings for the other tests where there may be additional dilution due to natural excursion of the tracer gas from one end of the room to the other. A possible re-interpretation of this particular test, using global effects from the other tests as well, can be that the tracer gas movement with the source located in the lefthand portion of the room is strongly affected by the positive pressure gradiant across the battery room doors. That is low readings at station C2 and C3 for this test are not caused by the dilution effect of the exhaust port located on top of the battery room but possibly because a large fraction of the tracer gas had been injested into the battery rooms. Note also that readings at sample location B21, which were taken at chest height are in some instances larger than the ceiling values taken at the same grid point. And also, the higher readings on top of the battery room for test performed with the simulated fires at the righthand portion of the room is because the tracer gas was more apt to be affected first by the HVAC system located near the ceiling.

Finally, the normalization procedure that is used in presenting the raw data complicates test by test comparison. Another factor which has made timewise comparison of a given test difficult is the unsteady behavior of the SF_6 source (a factor which must be corrected if tests such as this are to continue) since one cannot now ascribe tracer gas buildup in a given area due to possible re-entrainment of SF_6 as a result of the circulatory flow patterns within the room on due to the unsteady character of the source. In addition, determining those locations which first sense the tracer gas is only part of the overall problem in smoke detector site location since there is a complex inter-relationship between the physical properties of real smoke, viz, particle density, size distribution, aging, and mass concentration and the alarm threshold of smoke detectors. However, as the state-of-the-art now stands, if tests, like NUTECH's, show areas in the test room where tracer gas concentration increases rapidly, tends to stabilize, and then rises again, while contiguous areas are relatively stable by comparison, then one can ascribe this trend to either the global circulation pattern within the test area as the possibility for this re-entrainment process or due to localize turbulent eddy behavior and not because of unsteadiness in the soruce. Placement of smoke detectors in areas having the aforenoted SF_6 concentration trends, together with the effects of smoke on detector threshold response as are currently being investigated at NBS, will lend more credance to the necessary valued judgements in detector citing.

Accordingly, we would suggest that your staff recommend the following action items:

- Repeat test 2 or 4 with samples stations concentrated in the lefthand portion of the room; check for repeatibility.
- Take readings <u>within</u> the battery room near the door.
- Take readings at each of the room exhaust ducts.
- Additional sampling points at 5 feet elevation above the floor to reveal aspects of favorable smoke detector location that are not apparent from sampling data taken near the ceiling.
- Measure SF_6 concentration directly above source (approximately 3 feet above source) and use these data for reference.
- Provide assurances that SF_6 source is constant as well as heater output.
- Record air temperatures above source with a thermocouple probe which is shielded from the thermal radiation of the electric heaters.
- Measure air flow and temperature in the test room (for example using a hand-held device such as ETA model 100VT) at various select stations. These data, coupled with SF_6 measurements, may give a clearer picture of the simulated smoke distribution.

In overall summary the following factors may be gleaned from this report:

1. It represents the concerted efforts of I. Asp, J. Klevan, I. Pinkel, and myself in evaluating the basic NUTECH methodology and tests for smoke detector siting.
2. It indicates that the NUTECH approach can, in principle, quantitatively determine smoke migration within areas dominated by HVAC systems. However more sampling locations are required to determine the more suttle aspects of smoke migration. As to the economics of such an approach, this is a question which can only be answered by the utility proposing to use the method.
3. It shows, however, that the overall test methodology cannot verify that products of combustion from a fire would be promptly detected. Verification, as indicated, is considered beyond present day state-of-the-art technology and is not because of the direct limitations of the approach.
4. It recommends that, because of the exigencies placed upon the utilities by NRC, Section 4.2 of the cited SER should be changed to reflect present day state-of-the-art technology in smoke detector siting. A suggested rewording is enclosed.
5. It outlines current and future research being undertaken at NBS in the correspondence between detector response and the properties of smoke. It suggests that the NRC and the utilities consider this research as a complementary study with the recommendation that support should be

given to NBS for those aspects of the generic problem in threshold response which are germane to the problem at hand. Those problem areas have been described herein.

Finally, in order for us to comment on the NUTECH approach it had been necessary to explicitly define what is expected of their work. We believe the approach to be a viable one with great potential and, as such, the requirements stated by NRC for in situ tests should not exceed the potential of the proposed method. For, if more is demanded than existing techniques or information can supply than a useful approach to study smoke migration, which should provide some major benefits now, may have to be discarded. We do not wish this to happen.

Yours truly,

John Boccio

John Boccio
Reactor Engineering Analysis

JB:sd
enclosure
cc.: I. Asp
R. Cerbone
R. Hall
W. Kato
J. Klevan
V. Panciera
I. Pinkel

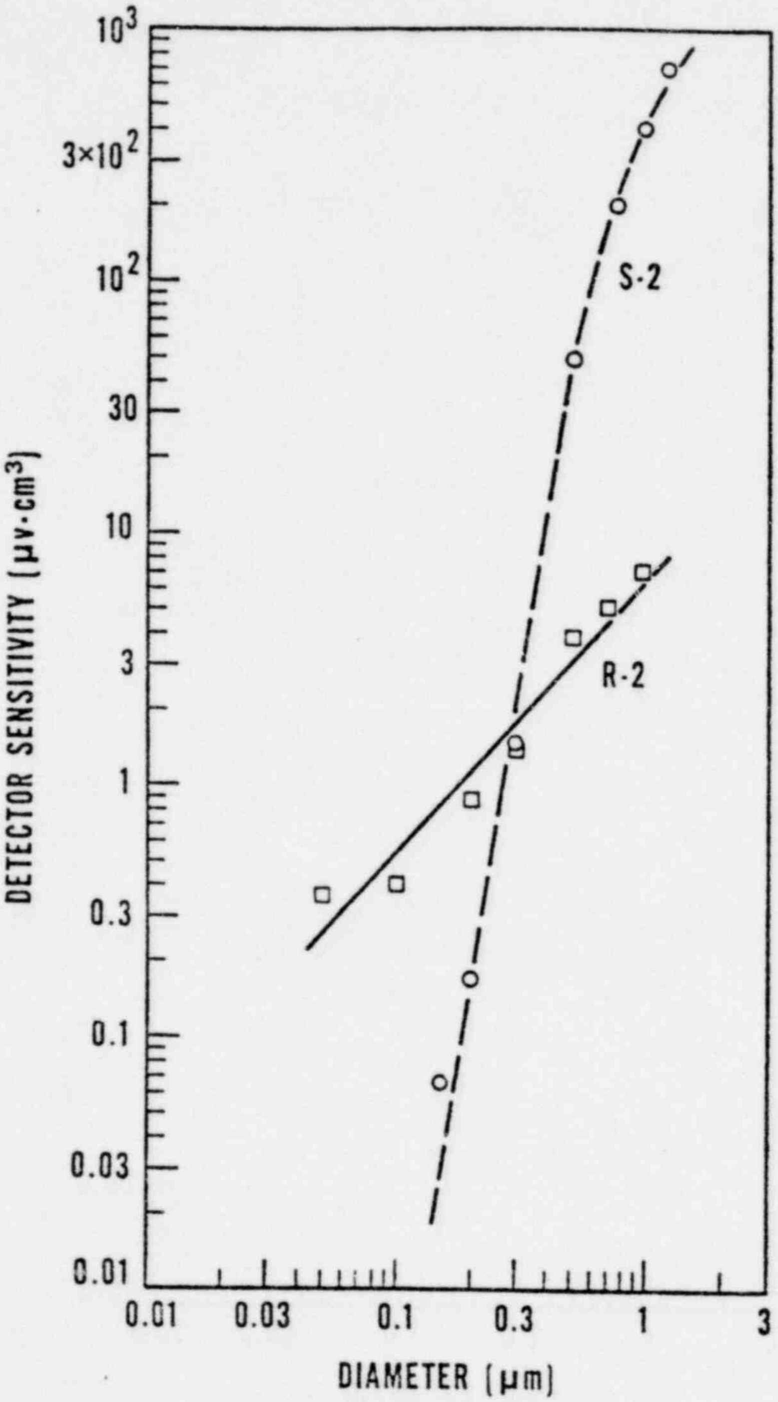

Figure 1. Detector sensitivity versus particle size for a light-scattering type detector (S-2) and for an ionization type detector (R-2) [15].

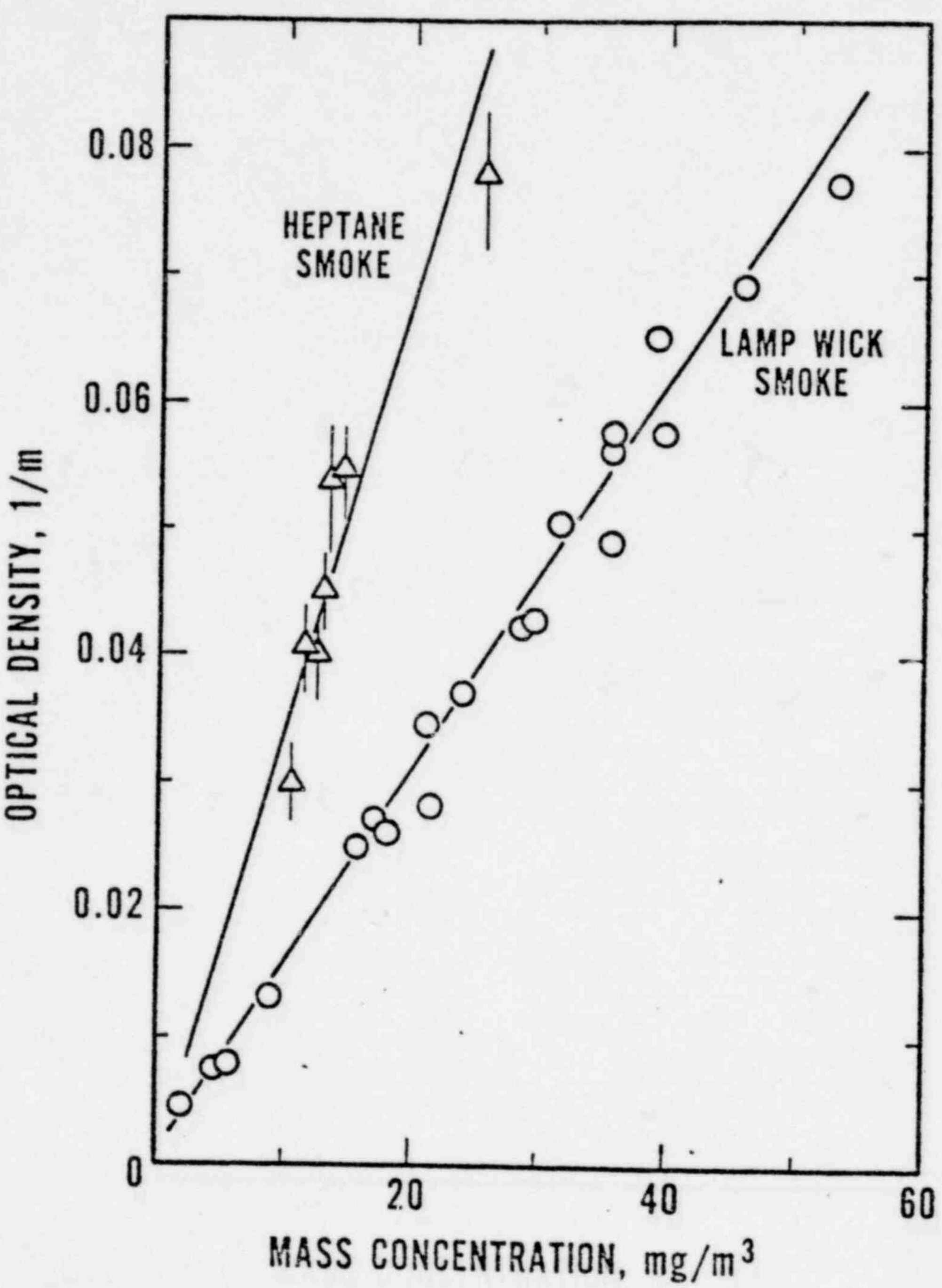

Figure 2. Optical density per meter versus mass concentration for lamp wick smoke and heptane smoke [20].

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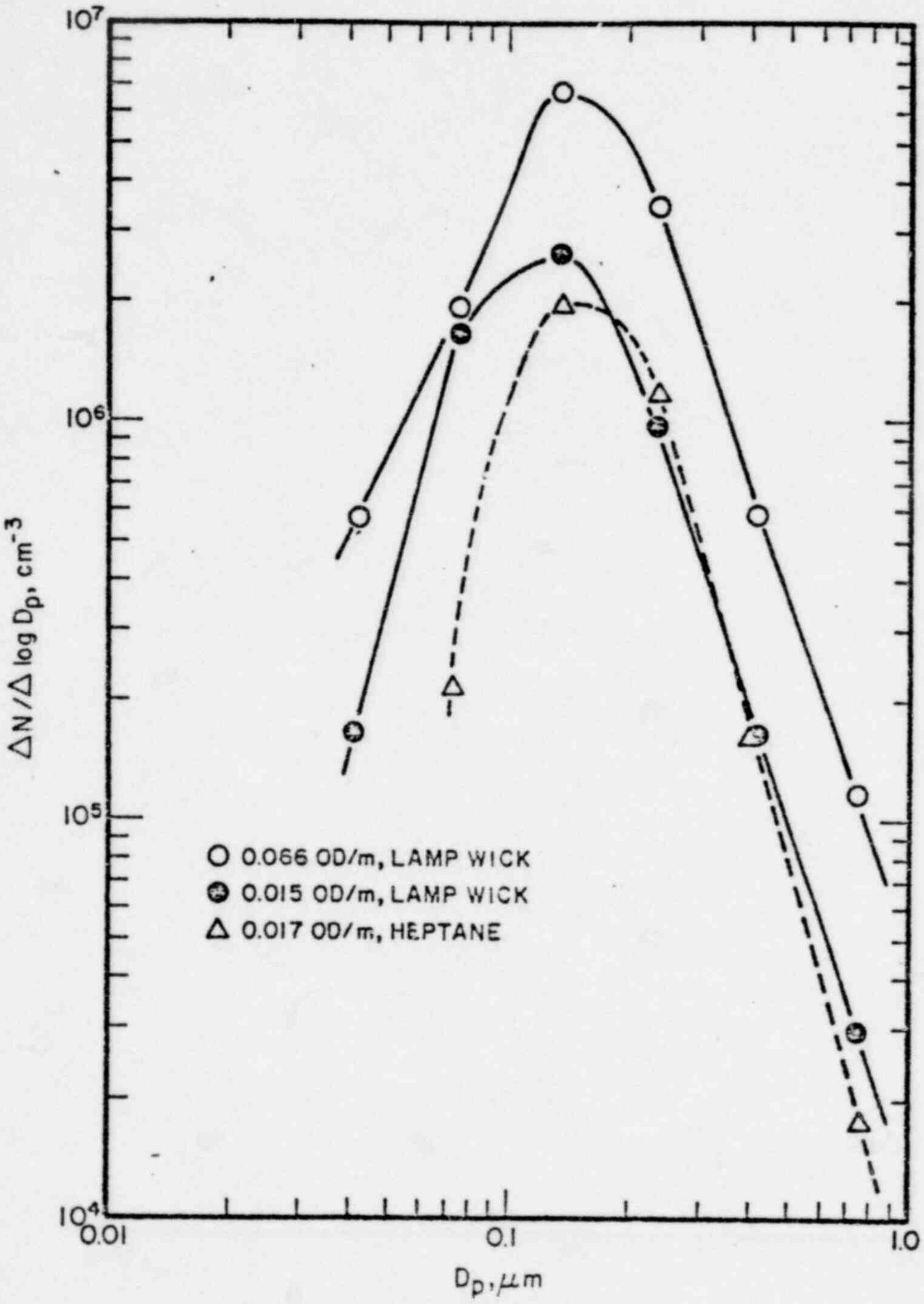

Figure 3. Particle size distribution for lamp wick and heptane smokes [20].

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	1	2	3	4	5	6	7
A		6	10	2	4	10	
B	0	10	8	0	2	4	0
C		4	0	0	6	0	8

Figure 4. Detector Site Priority

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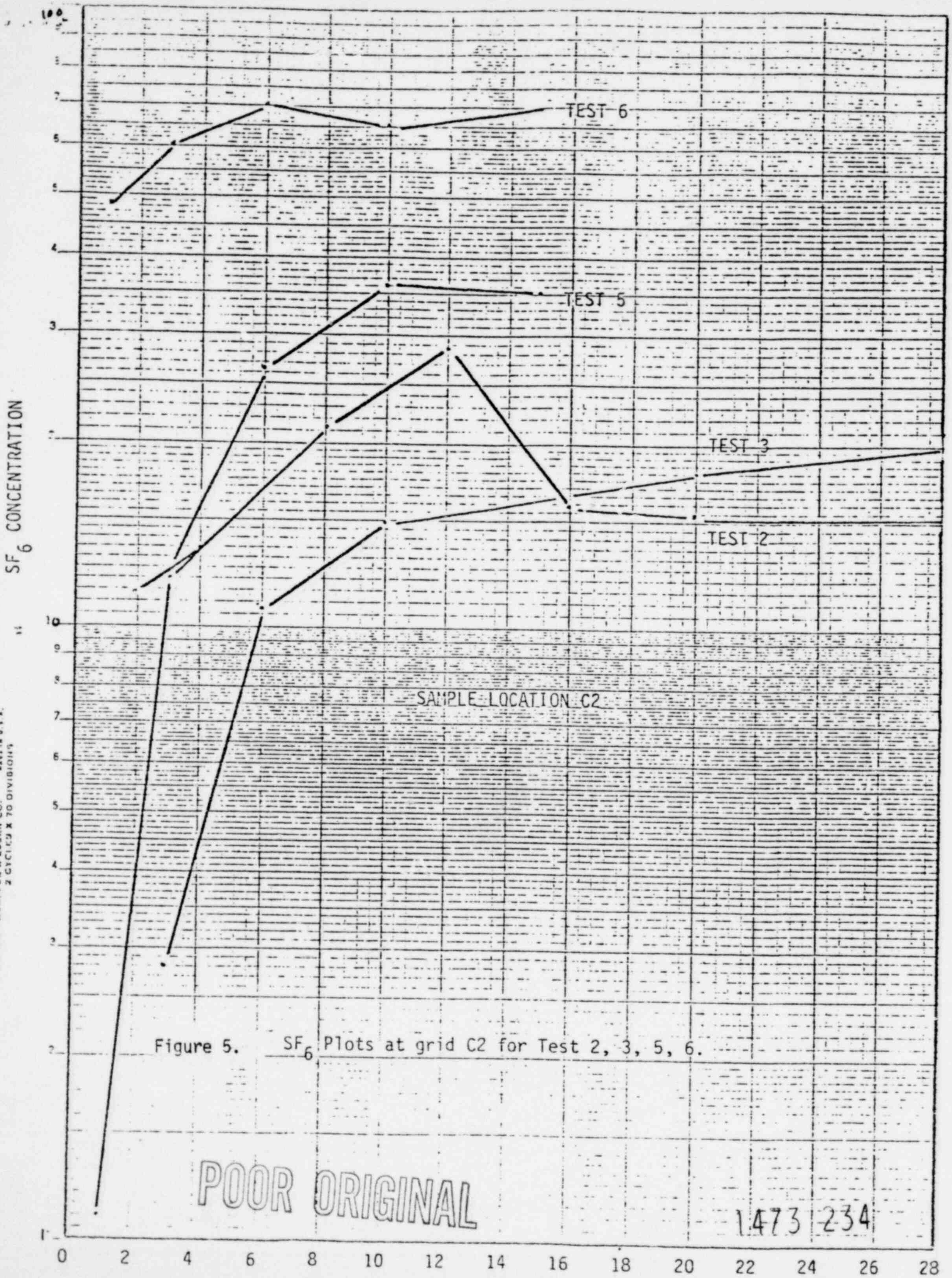

Figure 5. SF$_6$ Plots at grid C2 for Test 2, 3, 5, 6.

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