Received w/Ltr Dated 9-12-68

Regulatory Suppl File Cy.

U. S. Atomic Energy Commission

Docket No. 50-286

Exhibit B-7

CONSOLIDATED EDISON COMPANY OF NEW YORK, INC.
INDIAN POINT NUCLEAR GENERATING UNIT NO. 3

SEVENTH SUPPLEMENT TO:
PRELIMINARY SAFETY ANALYSIS REPORT

REGULATORY DOCKET FILE COPY

DOCKETED
USAEC
DEC 9 1968
REGULATORY
MAIL SECTION
DOCKET ENTRY

RECEIVED
DEC 9 1968
U.S. ATOMIC ENERGY COMMISSION
Regulatory
Mail Section

8110300260 681209
PDR ADOCK 05000286
B PDR

REGULATORY DOCKET FILE COPY

5212

PREFACE

Supplement 7 to the Indian Point Unit No. 3 PSAR consists of responses to the AEC questions of November 20, 1968. The questions deal with the following areas:

1) Flooding at the Site
2) Tornado Provisions
3) Internal Missiles
4) Rod Ejection Accident
5) Design Basis Accident
6) Electrical Power, Instrumentation and Control, Cable Routing, and Radiation Monitoring

Question 1 (Part 1)

Present details of your calculations of flooding at the site. Consider both the flood resulting from heavy rainfall in the watershed of the Hudson River concurrent with dam failure and that resulting from the occurrence of the probable maximum hurricane.

Answer

A. For the Flood Condition Resulting from Heavy Rainfall Concurrent with Dam Failure

Determination of Flow

The flood flow under this condition will include three components which are additive.

The first of these components is the tidal flow occurring at ebb tide. Velocity measurements at Peekskill have shown the maximum ebb flow can reach 275,000 cfs.[1]

The second flow component results from dam failure of Sacandaga, Indian Lake, Hinkley, Gilboa and Ashokan Reservoirs, the largest reservoirs in the basin. Indian Lake, Hinkley and Gilboa Reservoirs are all farther from Indian Point than is Sacandaga. Conservatively high flows were obtained by locating these three reservoirs at Sacandaga.

Sacandaga Reservoir is located 200 miles upstream of Indian Point. This reservoir is operated by the Hudson River - Black River regulating district. Combined volume of these four reservoirs is approximately 50 x 10^9 cubic feet.

Ashokan Reservoir is located 50 miles upstream of Indian Point. This reservoir is operated by the New York City Board of Water Supply and has a capacity of 18 x 10^9 cubic feet.

---

[1] Quirk, Lawler & Matusky Engineers- "Hudson River Dispersion Characteristics" - Progress Report to Consolidated Edison Co. of New York, October 1965

Flow associated with dam failure at each reservoir was computed by dividing the total reservoir volume by the emptying time. Analysis has shown the emptying time of the reservoir to be in the order of one day.

Both dams were assumed to fail so that the two computed flows would arrive at Indian Point simultaneously.

The flow due to dam failure is 785,000 cfs.

This approach is considered to be very conservative. This flow really only represents the average flow past the broken dam. As the water moves downstream and spreads out, it is stored over the vast surface area between the dam and Peekskill. Since the total volume of water is limited to the reservoirs' contents, the computed flows cannot be maintained.

This siutation was also analyzed as the traveling wave of water using standard techniques.[2]

An 8 foot wave was computed, which would be added to the River depth computed for all the other flow components. Total depth using this procedure was substantially lower than that obtained using 785,000 cfs for the dam failure flow component, in conjunction with the other flow components.

The third flow component is the runoff resulting from heavy rainfall over the basin drainage area.

Although no study has been undertaken to determine the probable maximum precipitation for the Hudson River Basin, one has been completed for the adjacent Susquehanna Basin.[3] Since the basins have similar topography and are adjacent, the findings and procedures outlined in this report were used to determine a probable maximum rainfall of 14" in 72 hours for the Hudson Basin at Indian Point.

Applying this rainfall over the tributary drainage area at Peekskill with a rainfall-runoff coefficient, C, of 0.5, the resulting flow is 660,000 cfs. This is more than two times the estimate for the maximum flows at Indian Point based on

---

[2] Chow, V.T. "Open Channel Hydraulics" - McGraw Hill Book Co. Inc. (1959)

[3] Hydrometeorological Report No. 40, "Probable Maximum Precipitation, Susquehanna River Drainage Basin, Above Harrisburg, Pa." Hyrometeorological Branch, Office of Hydrology, U.S. Weacher Bureau, (May 1965)

observed data.[4]

The total flow at Indian Point is the addition of the three components summarized in the following table:

Component Flow at Indian Point

1)	Maximum ebb tide	275,000 cfs
2)	Flow caused by dam failure	785,000 cfs
3)	Flow caused by maximum rain	660,000 cfs
4)	Total flow at Indian Point	1,720,000 cfs

The total flow used in determining the rise in water elevation at Indian Point is 1.72×10^6 cfs.

Determination of the Water Elevation

The determination of the water elevation at Indian Point employed the use of the Manning Open Channel Flow Equation. The analysis involved a trial and error solution of the channel depth for a known flow. The application of the Manning Equation is valid since it can be shown that the Hudson River at extreme flow behaves as an open channel under uniform flow conditions.

For the maximum flow of 1.72×10^6 cfs and a roughness coefficient, n, of 0.03[5], the channel depth will be 58.5 ft. This is equivalent to a rise in the ebb stage water elevation of 16.5 ft. Relating this to msl datum, the design elevation will be less than 16 ft.

The normal channel width of 4,000 ft. was used with the assumption that this would remain constant as the water elevation increased. This is a conservative approach in that it does not allow for the lateral spread in the water.

---

[4] The estimate is based on a drainage area ratio between Troy & Indian Point and the maximum recorded instantaneous flow at the Green Island gage (near Troy) of 181,000 cfs. The estimate for Indian Point is 285,000 cfs.

[5] Chow, V.T. "Open Channel Hydraulics" - McGraw Hill Book Co., Inc. (1959) p. 112

The channel slope was determined to be 0.0001 and constant.

The following table summarizes the results of this analysis:

Maximum Downstream Flow (cfs)	Channel Depth (ft)	Rise Over Normal Water Elevation (ft)	Design Elevation (msl datum)
1,720,000	58.5	16.5	<16

These results are conservative and a more refined analysis would result in a lower water elevation. Because the subsequent hurricane surge analysis proved to be controlling, additional analysis was not undertaken.

B. The Water Elevation Resulting From the Occurrence of Probable Maximum Hurricane at Indian Point

The probable maximum hurricane (pmh) for zone 4, lattude 41°N, as defined by the United States Weather Bureau[6], has the following meteorological characteristics.

Central Pressure	27.26" high
Forward Speed	8 to 48 knots
Radius to Maximum Winds	8 to 49 Naut. Mi.
Maximum Wind Speed	124-136 mph

For this hurricane, procedures published by the U.S. Army Coastal Engineering Research Center [7] were used to determine the surge height at Indian Point. Hurricane surge at Indian Point using these procedures is 16.8 ft.

With the addition of spring high tide, the surge reaches a maximum height of 19.3 ft. Details of the analysis are given below.

Parameters used included a forward speed of 34 knots, a radius

---

[6] Interim Report - Meteorological Characteristics of Probable Maximum Hurricane, Atlantic and Gulf Coasts of the United States. U.S. Department of Commerce, Weather Bureau 10/2/68

[7] U.S. Army Coastal Engineering Research Center, "Technical Report No. 4 - Shore Protection, Planning & Design" - 1966 p. 129-144

to maximum winds of 24 nautical miles, and a maximum wind speed of 127 mph. These values represent the conditions, within the ranges given for the pmh, for which maximum surge will occur.

Summary of Procedures Employed

The initial step involves the construction of the isovel field for the meteorological characteristics of the pmh. The field was constructed using standard procedures developed by the US Weather Bureau in the aforementioned report.

Following the construction of this field, the wind stresses for several lines passing through the hurricane and parallel to the direction of its movement were computed. The stress coefficient, K, for a hurricane moving over a sloping bottom, was used. The maximum wind stresses occur on a line which passes through the radius of maximum winds.

The maximum wind stresses were routed along several tracks along the Atlantic Coast, to determine which track would produce the highest surge at Sandy Hook. After selecting this critical hurricane track, the maximum hurricane stress was then routed through New York Harbor and up the Hudson River.

By routing the hurricane along this track, the maximum surge at Indian Point is computed to be 16.8 ft.

The resulting surge and water elevations for the probable maximum hurricane moving along a critical track to Indian Point are summarized below:

Water Elevation at Indian Point

	Elevation above msl (USC&GS)
Predicted Astronomical Spring High Tide[8]	+ 2.5
Probable Maximum Hurricane Surge	+16.8
Maximum Water Elevation at Indian Point	+19.3

---

[8] Tide tables East Coast North & South America. U.S. Department of Commerce, Environmental Science Service Administration, Coast and Geodetic Survey, 1968

This hurricane analysis is conservative since it was developed primarily for the open coast and neglects shear stresses along the river channel walls. Inclusion of these forces would attenuate the surge. Maximum observed river stage at Indian Point is 7.4 feet above msl.[9]

For the condition of high spring runoff concurrent with pmh surge control at the Battery, the maximum water level elevation at Peekskill is less than the 19.3 feet level obtained by routing the hurricane along the Hudson River track. Backwater computations show no significant rise in the water level at Indian Point under these conditions.

This hurricane surge elevation of 19.3 ft. exceeds the 16' elevation computed for the flood runoff condition and is therefore considered to be the controlling elevation for flood protection.

The surge analysis employed was developed for the open sea.[7] During the course of design, a more refined analysis of the flooding condition due to hurricane surge will be made. This will include:

1. Effect of side-wall friction on the surge as it moves up the Hudson River.

2. Possible increased bottom friction due to shallow River depths and correspondingly steeper vertical velocity gradients. The open sea analysis was developed for situations in which the depths are considerably greater than the River depths.

3. Recognition that the surge up an estuary is less at the time of high water than it is at the time of low water, and it decreases as the range of tide (spring conditions) increases.[10]

4. Determination of the actual percentage reduction

---

[9] U.S. Coast & Geodetic Survey, River Stage Elevation in Peekskill Harbor - Recorded - November 25, 1950

[10] Proudman, J., "The Effect of Friction on a Progressive Wave of Tide and Surge in an Estuary." Proceedings of the Royal Society, Vol 233A, pages 407-418 (1955)

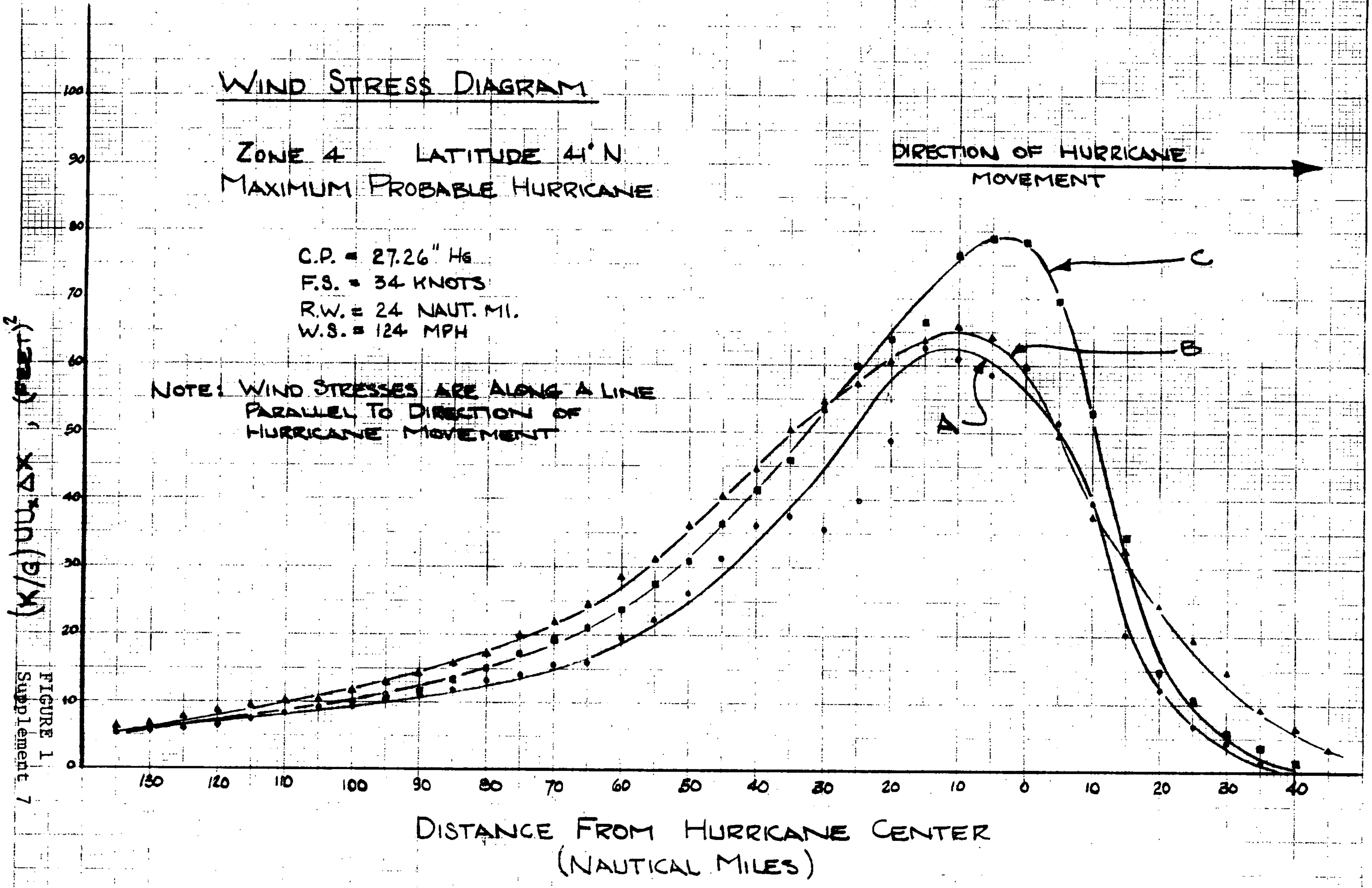
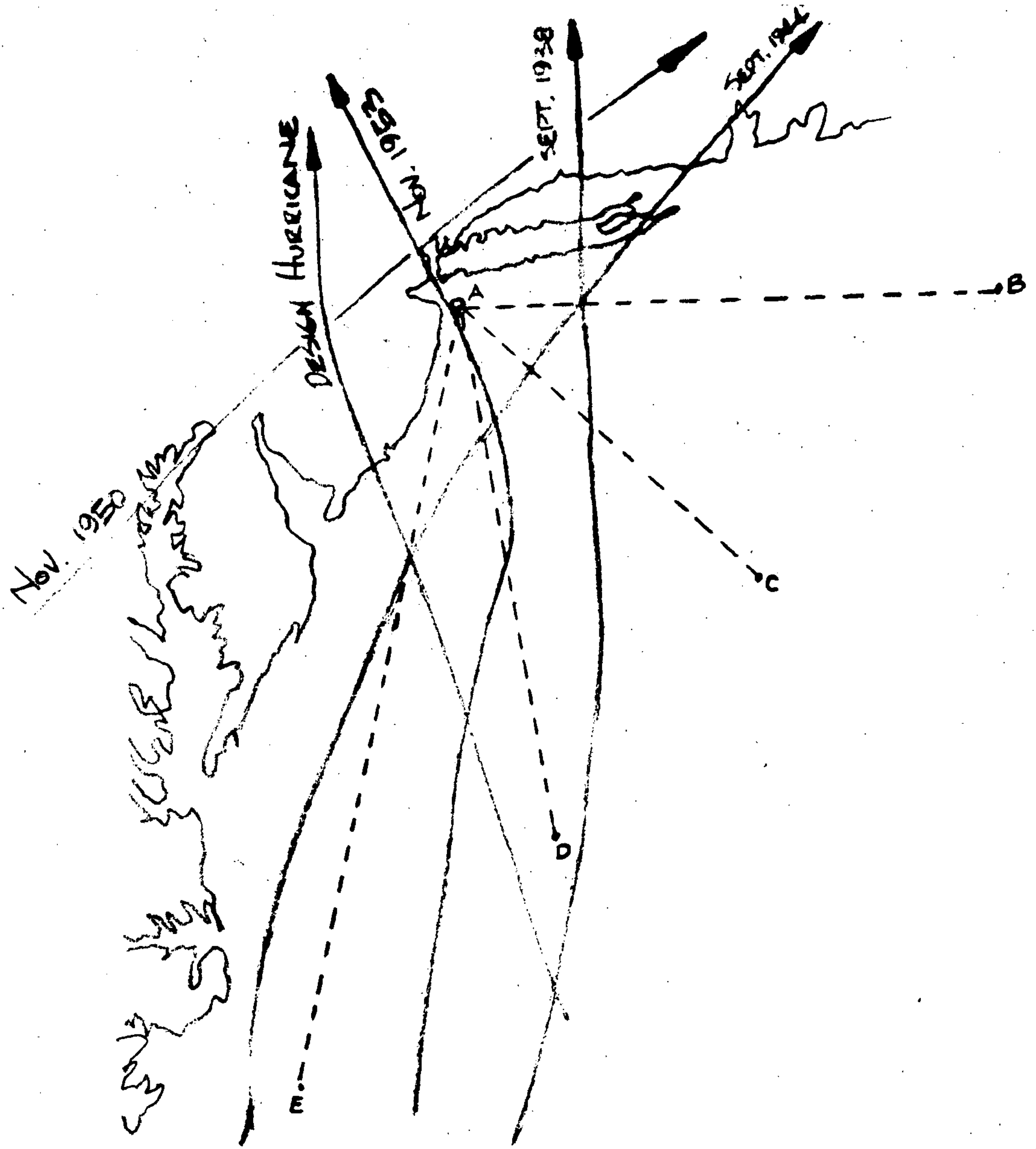


FIGURE 1
Supplement 7



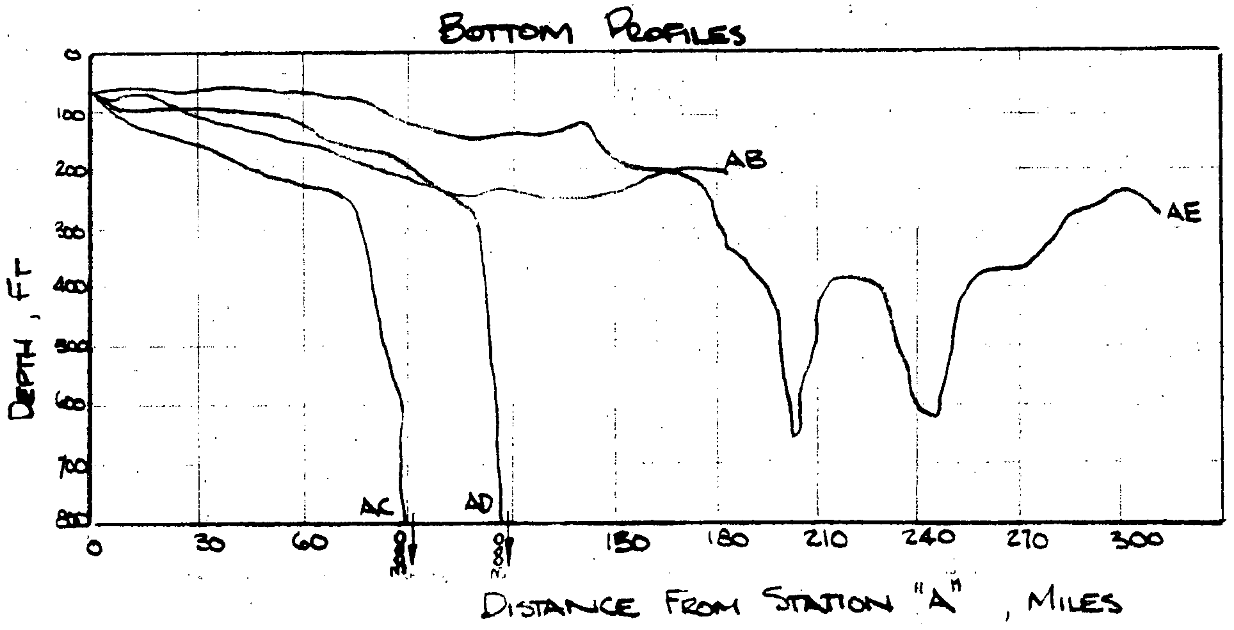


FIGURE 2
Supplement 7

FIGURE 3
Supplement 7

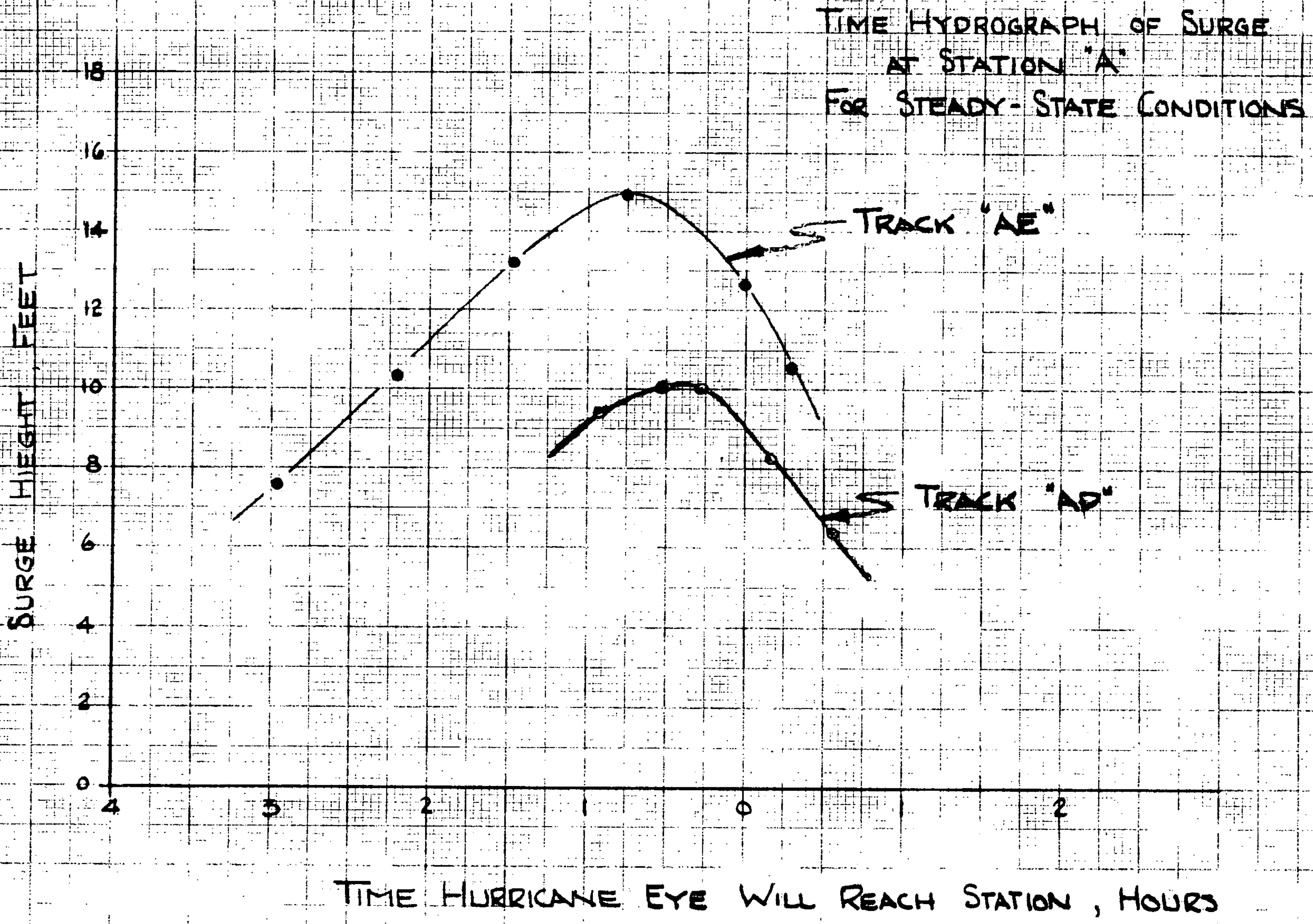
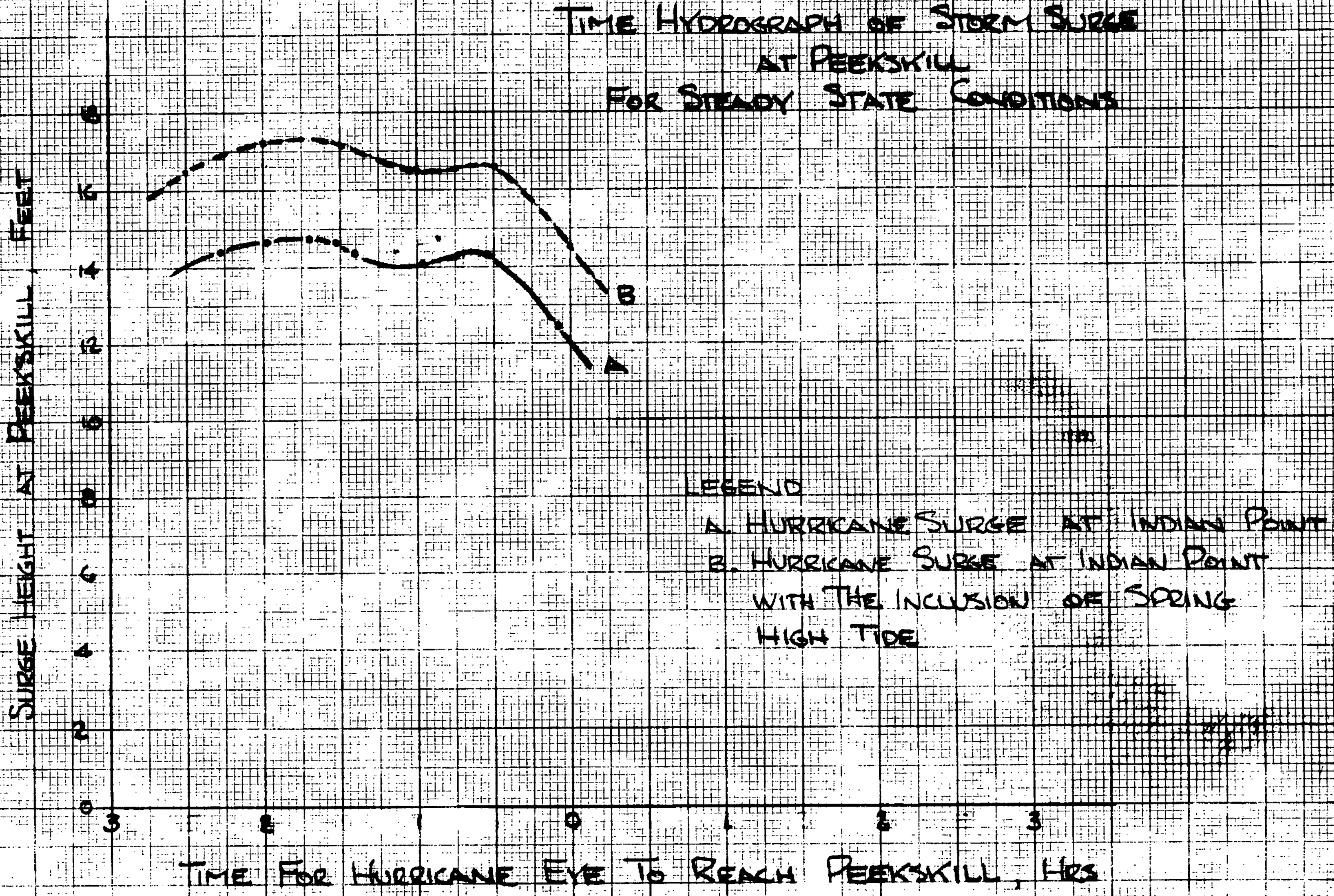

TIME HYDROGRAPH OF SURGE AT STATION "A" FOR STEADY-STATE CONDITIONS

FIGURE 4
Supplement 7


TIME HYDROGRAPH OF STORM SURGE
AT PEEKSKILL
FOR STEADY STATE CONDITIONS

> in hurricane winds by movement 50 to 60 miles inland. Values used in the preceding analysis were given in Reference 7 as useful for 10 miles inland or more.

These refinements will most probably result in a significantly lower maximum hurricane surge level at Indian Point. Should this be so, the conditions of heavy rainfall and dam flooding, and of surge control at the Battery, will also be reviewed in determining the controlling flood condition.

QUESTION 1 (Part 2)

Discuss the ability of the intake structure to withstand the impact of marine vessels which may be present in the vicinity of the plant at the time the flood occurs.

ANSWER

It is to be noted that the study of the hydrology of the site indicates a potential for a water level at the site of 19.3'under the most severe predictable but almost incredible conditions of storm activity. Under these conditions, should one of the ocean craft moored nearby in the Hudson river become free and driven by the storm toward the intake structure, there would be no reasonable way of preventing it from demolishing the structure and with it most probably the service water supply.

In view of this and since there would be ample warning of a storm of such potential, administrative procedures will be established which will call for the plant to be shut down and placed in a safe condition in the event water level reaches elevation 14.0'.

To insure the ability to maintain the plant in a safe condition, the design will incorporate the following features:

1. An alternate service water supply system which will be located such that it cannot be disabled by the consequences of such a storm.
2. The ability to prevent equipment critical to this situation from being jeopardized by water at an elevation of 19.3'.

During the course of design, should the refined flooding analysis show the maximum water level is lower than the 19.3 ft., the design provisions will be adjusted accordingly.

QUESTION 2

In your PSAR as amended, it is stated that a tornado would not (1) cause a loss of coolant accident, (2) impair the ability to shut the plant down, and (3) impair the long-term safety of the plant following a loss of coolant accident. What additional criteria have you established regarding protection of vital structures, systems and components, so that the design tornado or missiles associated with it should not cause other accidents which could release significant radioactivity to the environs? With regard to the ability for safe plant shutdown in the event that a tornado causes a loss of off-site power, what protection is provided to the emergency power system (including the diesel generators) from tornado effect?

ANSWER

The design of Indian Point Unit No. 3 considers accident analyses for systems which can release radiation to the environs. Section 12 of the PSAR gives the expected doses for the accident cases. Further accident analyses resulting in radiation releases are found in Supplement 1, Items 2 and 16, and in Supplement 5, Item 14. These analyses show that the off-site consequences are within acceptable limits.

The doses calculated in the analyses were based upon the short-term meteorology for the site. If higher wind velocity is assumed in the analyses, the χ/Q would be proportionally lower and the exposure time would also be lower. The resultant doses would thus be lower than those reported above and factors of 10 to 50 lower could be realized.

The diesel generator building will be a tornado proof structure. Furthermore, the structure will be provided with internal walls to separate the diesel generators and their associated cabling and switchgear for fire protection.

The remaining components of the emergency power system are either underground or are housed in tornado proof structures.

QUESTION 3

Analyze the consequences of a missile generated by rotating machinery (such as a main coolant pump flywheel) striking critical portions of the primary or secondary system.

ANSWER

There is no rotating machinery inside the containment that is a source of high-energy missiles.

Precautionary measures, taken to preclude missile formation from primary coolant pump components, assure that the pumps will not produce missiles under any anticipated accident condition.

The primary coolant pumps run at 1200 rpm, and may operate briefly at overspeeds up to 110% (1320 rpm) during loss of outside load. Analyses of turbine dynamic characteristics for the Indian Point reactors indicate that, given failure of the turbine governor to respond immediately upon loss-of-load, backup valves would prevent overspeeds greater than 113%. For conservatism, however, 125% of operating speed was selected as the design speed for the primary coolant pumps. For the overspeed condition, which would not persist for more than 30 seconds, pump operating temperatures would remain at about the design value.

Each component of the primary pumps has been analyzed for missile generation. Any fragments would be contained by the heavy stator. The same conclusion applies to the impeller because the small fragments that might be ejected would be contained by the heavy casing.

The primary coolant pump flywheels are shown in Figure 3-1. As for the pump motors, the most adverse operating condition of the flywheels is visualized to be the loss-of-load situation. The following conservative design-operation conditions preclude missile production by the pump flywheels. The wheels are fabricated from rolled, vacuum-degassed, ASTM A-533 steel plates. Flywheel blanks are flame-cut from the plate, with allowance for exclusion of flame-affected metal. A minimum of three charpy tests are made from each plate in accordance with ASME specifications, to determine that each blank satisfies design requirements. An NDTT less than +10°F is specified. The finished flywheels are subjected to 100% volumetric ultrasonic inspection. The finished machined bores are also subjected to magnetic particle, or liquid penetrant examination.

These design-fabrication techniques yield flywheels with primary stress at operating speed (shown in Figure 3-2) less than 50% of the minimum specified material yield strength at room temperature (100 to 150°F). Bursting speed of the flywheels has been calculated on the basis of Griffith-Irwin's results(1), to be 3900 rpm, more than three times the operating speed.

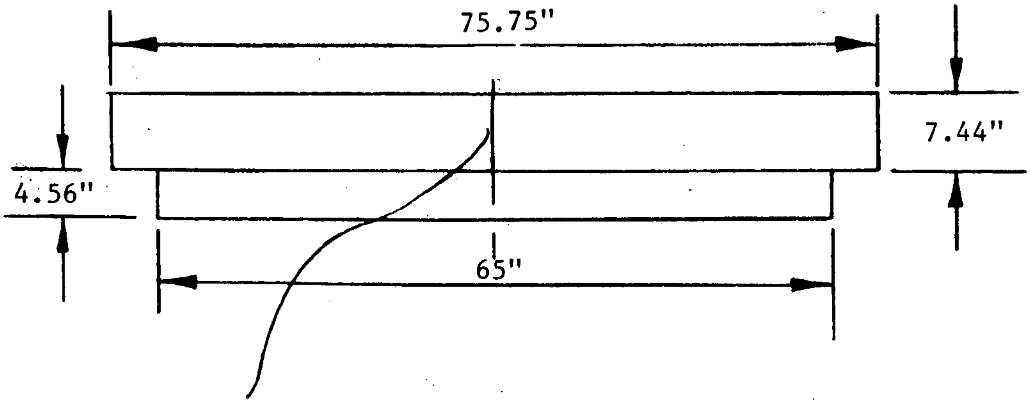
In order to preclude undetected flywheel deterioration during plant life, even though such deterioration is not expected, the ultrasonic inspections are repeated at intervals during plant life.

Therefore, it has been concluded that the reactor coolant pumps, are not sources of missiles and the engineered safeguards are not in jeopardy.

---

(1) Ernest L. Robinson, "Bursting Tests of Steam-Turbine Disk Wheels", Transactions of the A.S.M.E. July 1964.

FLYWHEEL



Bore of ∿ 8-3/8" Diameter with 3 Keyways

FIGURE 3-1

Supplement 7

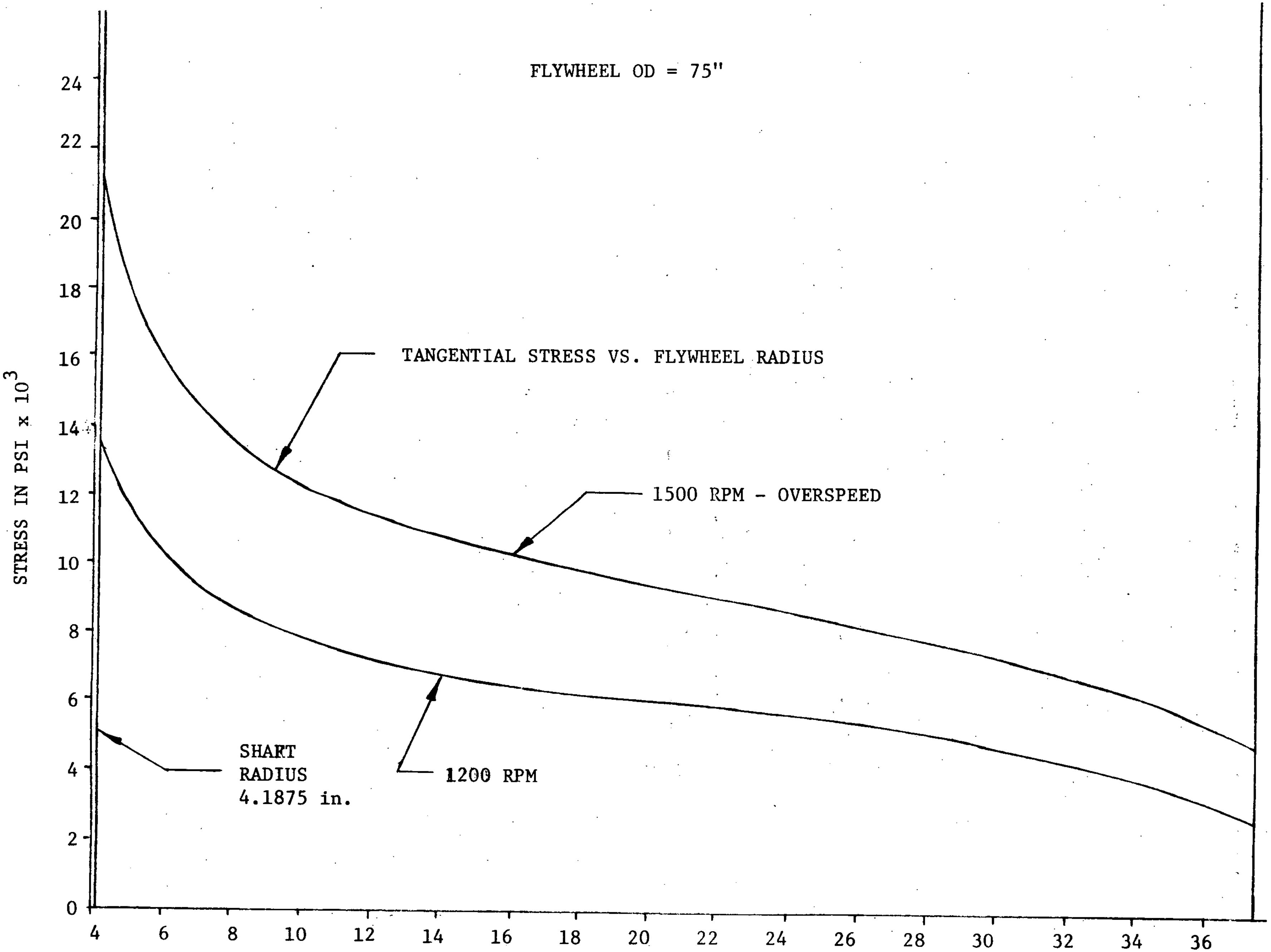


FIGURE 3-2
SUPPLEMENT 7

QUESTION 4

The rod ejection accident analysis in the PSAR refers to the analysis presented in the Indian Point Nuclear Generating Unit No. 2 PSAR. Supplement this information by discussing (1) the effect the gain in reactivity worth experienced by a fully inserted rod has on the consequences of this accident and (2) the mechanical effects on the fuel elements if this accident were to occur while operating with the maximum number of failed fuel elements which you will propose in establishing primary coolant activity limits in your technical specifications.

ANSWER

(1) Under normal operating conditions, only the X-Y xenon control rods can be fully inserted at full power. The mode of operation of these rods is such that they will be withdrawn within about 4 hours, i.e., before the local xenon peak is reached. The ejected rod worth and transient hot channel factor will progressively decrease over this period.

Detailed rod ejection physics calculations are not yet available for this plant. However, experience gained from other plants, including Indian Point Unit No. 2, indicates that at full power, the reactivity worth of a single fully inserted rod will certainly be less than 0.5 % ΔK. In the event that any rod is dropped at full power, its presence will be promptly noticed and immediate remedial action taken.

A large population of waterlogged fuel rods is not expected in a Westinghouse pressurized water reactor at any time. The reactor design expectation is less than 0.1% leaking fuel, but from the point of view of fission product release to the coolant, analyses are based on pinhole leaks in the equivalent of 1% of all fuel rods.

Because the UO_2 fuel is in pellet form, any water that enters through leaking clad will not mix intimately with the fuel, but will only gather in the gap between fuel and clad and in the interstices between pellets and beteween fragments of cracked pellets. The gap provides a path for escape of water and steam as the fuel is heated during normal power escalation. Thus, when the reactor is producing significant power, even the failed fuel would be dry, and failures would have no effect on the course of a rod ejection accident. Therefore, the consequences of a rod ejection accident from power operating conditions are those discussed in the PSAR, with or without failed fuel.

(2) During a sudden power increase from a power level low enough to permit the presence of water in the defected fuel rods, epitomized by a control rod ejection accident, rupture of some defected fuel rods may occur.

Although no analysis of clad rupture has been performed, experiments at SPERT indicate that the failure threshold of pelletized fuel may be as high as 250 cal/g of UO_2 averaged radially in the fuel rod. Because of the expected small number and random distribution of defected fuel rods, and the sharply peaked power distribution associated with a low-power rod ejection, only a small fraction of the failed fuel rods would be expected to rupture during the worst accident. These ruptures would be expected to occur as isolated events during and after the power burst, and the pressure waves generated by the sudden release of steam would appear as isolated pulses. SPERT experiments imply that the resulting pressure generation would be destructive only in the immediate surroundings of each failed rod, if at all. Because of the small number of such fuel rods, the magnitude of the pressure wave would be insignificant compared to the pressure rise otherwise expected from prompt moderator heating and normal heat transfer.

Experience at SPERT also indicates that failure would occur first at the axial hot spot of each fuel rod. The resulting dispersal of fuel in a high-worth region of the core would cause an immediate negative reactivity contribution due to the increase in resonance absorption by the dispersed fuel. If fuel is also ejected from the ends of the rod toward the break, the increased fuel concentration at the axial hot spot would also cause a negative reactivity contribution. The associated steam void, which would appear in a high-worth region of the core, would also cause a negative reactivity contribution since the moderator void coefficient is everywhere negative (and becomes increasingly negative with burnup as the potential ejected rod worth increases). Thus, the expected result would be a strong negative reactivity pulse at each rod rupture, tending to decrease the total energy generated during the prompt power burst below that calculated for intact fuel.

From these considerations, it is concluded that rod ejection with failed fuel in the core would, at worst, have consequences less severe than those discussed for the large coolant pipe break.

QUESTION 5

As discussed in our letter of February 19, 1968 and our meeting of November 6, 1968, the design basis accident doses evaluated by the staff do not meet the guideline dose levels recommended in 10 CFR 100. Please discuss the manner in which you intend to diminish these doses. If added equipment or modified assumptions are anticipated, please describe and provide an evaluation of the changes.

ANSWER

1.0 INTRODUCTION AND SUMMARY

A substantial body of experimental data has been reported (BMI-1829 and references) which shows that the fraction of volatile iodine which may appear in the form of organic iodine compounds following a fuel melt is quite small: of the order of a few percent of the total core inventory. The significance of this source of iodine in possible gas leakage from the containment is small relative to inorganic forms. The spray solution (alkaline sodium tetraborate) employed to remove inorganic iodine vapor, however, has little or no affinity for organic forms. Consequently, the existence of even a low yield of organic iodides, such as methyl iodide (CH_3I), can contribute an important part of the long-term dose, much of which is incurred after the inorganic iodine source is effectively eliminated by the sprays. A conservative calculation of the 30-day dose at the 1100 meter radius, where 10% of the containment atmosphere iodine burden as defined by TID-14844 is assumed to be organic, yields a value in excess of 300 rem if no removal of organics is achieved.

Although the conditions which could give rise to such a dose for the design basis containment leakage rate are extremely improbable, it was decided to provide additional safety features to reduce the concentration of radioactive organic iodides should they be produced in an accident.

The material which follows describes the use of iodized activated charcoal absorbers (filters) to decontaminate the containment atmosphere with respect to organic iodides. These filters are installed in the Air Recirculation Cooling and Filtration Units, and will process part of the air-steam mixture flow after it passes through the cooling coils, demister and HEPA filters, and before it is returned to the containment via the ventilation system distribution ducts. The filters affect organic iodide vapor activity by a process of isotopic exchange. For example, radioactive iodine associated with a CH_3I molecule which temporarily adsorbs the charcoal surface, interchanges with iodine pre-deposited on the charcoal. The CH_3I molecule later de-sorbs and leaves the charcoal bed, but on the average it will take on the specific activity of the idoine on the filter rather than that of the incoming vapor iodine. If the iodine on the filter is predominantly non-radioactive, a condition achieved by pre-depositing an excess of natural iodine compounds on the charcoal, then decontamination is achieved. Most of the CH_3I compound continues to exist in the vapor phase, however, the net retention of CH_3I by charcoal being incidental.

Three factors are important in selecting the size and type of filter units for this service:

1. The efficiency, or more correctly, the probability of exchange occurring per pass through the filter;

2. The rate at which the containment atmosphere is passed through the filters; and

3. The mass ratio of pre-deposited, inactive iodine to radioactive iodine available for exchange.

The probability of exchange is affected by the residence time and available surface in the charcoal bed. The former is improved by lowering gas velocity, increasing bed thickness, and by preventing interstitial flooding of the bed by entrained water. Available surface is favored with certain grades of charcoal, and also by minimizing the inventory of water in the bed. Here the dependence on water loading is more subtle. As will be explained in greater detail herein, the loss of adsorptive capacity exhibited by certain charcoals when brought to equilibrium with a saturated steam atmosphere affects only a fraction of the pore area. There remains a sufficiency of active area, exposing reactive iodine to the incoming air, to effect decontamination.

Experimental data to be presented show that useful capacity to achieve isotopic exchange with CH_3I exists both at the "saturation" water loading and at loadings well above this value approaching interstitial flooding.

Part 2.0 of this answer deals with the phenomenon of isotopic exchange with CH_3I, the data on its effectiveness under accident conditions and its sensitivity to water loading.

Part 3.0 describes the system and the charcoal filters incorporated in the Indian Point Unit 3 containment. Inasmuch as this constitutes a design change from that described initially in the PSAR for this Unit, the form of this section is that of a replacement section of the PSAR, superseding the description of the Containment Air Recirculation Cooling and Filtration System previously contained in that section.

Part 4.0 is an evaluation of the performance of the charcoal filters in reducing the dose effect of organic iodides in the containment leakage.

The following table summarizes the principal design characteristics of the charcoal filters. It will be noted that only a portion of the steam-air flow through each fan cooler unit is diverted through the charcoal filters. As was mentioned earlier, the significance of the organic iodine forms is felt in the evaluation of long-term leakage effects, when the otherwise dominant inorganic iodine vapor has been removed by sprays. The filtering rate is therefore determined by the need to reduce integrated average concentrations over the long term (30 day) dose period. The design relies upon the established capability of sprays to remove inorganic iodine vapor in the short-term (2 hour) period, thus avoiding the additional surveillance and handling problems of full-flow filter banks, and reducing the inventory of combustible material in the containment.

Section 2.0 which follows was prepared with the technical assistance of Dr. J. Louis Kovach, Vice President, Director of Research, North American Carbon, Incorporated.

TABLE 1

CHARCOAL FILTER DESIGN SUMMARY

Number of air handling units installed	5.
Minimum number of units operating, accident mode	3.
Number of charcoal filter banks per a.h. unit	1.
Number of charcoal filter cells per bank	12.
Minimum number of cells operating, accident mode	36.
Number of charcoal beds per cell	2.
Superficial flow area per cell, sq ft.	12.3
Approximate frontal velocity, accident mode, fpm	50
Approximate flow per cell, accident mode, cfm	620.
Approximate total filter flow, accident mode, cfm	22,320
Bed depth, in.	2.
Approximate superficial residence time, accident mode, sec.	0.2
Volume of packed charcoal per cell, cu. ft.	2.05
Minimum of packaged charcoal per cell, lb.	44.7
Wgt. % impregnated iodine	4.5
Wgt. of impregnated iodine per cell, lb.	2.0
Wgt. of impregnated iodine in minimum operating cell, accident mode, lb.	72
Wgt. of 50% core iodine inventory, maximum burnup status, lb.	20.

2.0 ISOTOPIC EXCHANGE UNDER ACCIDENT CONDITIONS

Background

In the evolution of nuclear power reactor designs, engineered safeguard systems have been developed to remove the fission product iodines from the containment atmosphere, following the hypothetical accident. Among these engineered systems, activated carbon filters have gained prominence as a means for removal of elemental iodine. The performance of these filter media of the post-accident environmental conditions has been well publicized in a number of review articles (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11).

With more emphasis placed on the possible existence of volatile organic iodides, the activated carbon filter medium in the form found suitable for elemental iodine removal, was evaluated with methyl iodide atmospheres. It was found that the physical adsorption of methyl iodide on plain activated carbon was strongly influenced by the water vapor content of the air stream and by the water content of the carbon in equilibirum with this air stream. It was found that above 30% relative humidity, the physical adsorption of methyl iodide decreases considerably at low temperatures, while adsorption from high temperature air-steam mixtures becomes insignificant (12, 13, 14, 15).

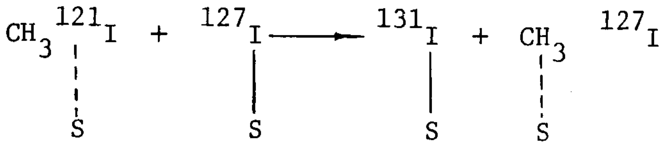
Development efforts at the Oak Ridge National Laboratories led to the investigation of activated carbons which were impregnated with various substances to enhance the removal of methyl iodide from humid air streams (16, 17, 18). Notable among the impregnates evaluated at ORNL was iodine. It was found that iodine-impregnated carbon had much improved methyl iodide decontamination properties, although methyl iodide itself was not removed, <u>per se</u>. **It was recognized that the treated carbons functioned** through the mechanism of isotopic exchange, i.e.,

$$CH_3\,{}^{131}I + {}^{127}I \text{ (on carbon)} \rightleftharpoons CH_3\,{}^{127}I + {}^{131}I \text{ (on carbon)}$$

It is important to realize that this process is reversible and the equilibrium distribution coefficients approximate the values expected from the relative ratio of the random distribution of ${}^{127}I$ and ${}^{131}I$ isotopic species of iodine.

The following possible mechanisms may occur:

1. The alkyl halide molecule is not chemisorbed except during the actual exchange which takes place with a chemisorbed iodine atom (or ion)



where S represents the surface.

2. The mechanism may be dissociative and involve adsorbed radicals (or ions) of the type CH_3^-.

As an example, with the $CH_3{}^{131}I \rightleftharpoons CH_3{}^{127}I$ exchange, it can be assumed that the following species take place in the reaction:

a, physically adsorbed methyl iodide
b, chemisorbed methyl radicals
c, chemisorbed ^{131}I atoms
d, chemisorbed ^{127}I atoms (bulk physically absorbed at high I_2/carbon loadings)

If it is assumed that no elemental ^{127}I is present on the carbon surface, but is introduced with the $CH_3{}^{131}I$ in the vapor form, the following will take place:

1. The surface concentration of each of the four kinds of species will increase and reach equilibrium values.

2. The exchange reaction will commence and will lead to isotopic equilibrium between the species in the system. The exchange reaction, Step 2, cannot be completed until all of the methyl iodide is adsorbed and desorbed. The only factor which reduces the rate of exchange from the initial value is the increase of the ^{131}I loading to that of the ^{127}I concentration. Thus the rate determining step (as long as a ^{127}I excess is present) is

the rate of adsorption and desorption of methyl iodide. In the case of methyl iodide, no difference in adsorption rates can be expected between $CH_3{}^{131}I$ and $CH\ {}^{127}I$ because the relative size and polarity of the molecules are identical.

Thus, both processes occur at the same rate and a convenient term of "adsorption/desorption" can be used.

Due to the fact that activated carbons retain relatively high quantities of elemental iodine, both ^{127}I and ^{131}I will be retained on the carbon surface. This permits the reloading of carbons with $^{127}I_2$ or $K^{127}I$.

In actual practice further complications arise from the presence of H_20 on the carbon surface which affects the rate of CH_3I adsorption. A detailed evaluation of this effect was made by Ackerman and Greas (19) for unimpregnated carbons. Differences from rate mechanisms of unimpregnated carbons can be expected in impregnated carbons due to the possible presence of iodine species in the liquid in the capillaries of the carbon.

EVALUATION OF AVAILABLE $CH_3{}^{131}I$ DECONTAMINATION DATA

A large amount of data concerning $CH_3{}^{131}I$ removal by impregnated carbons is available in the literature (11, 15, 17, 18, 20, 21, 22, 24, 25, 26, 27). In addition, current work is being described in the "Bimonthly Progress Reports of the ORNL Nuclear Safety Program".

In the following paragraphs, only data concerning commercially available carbons, impregnated with iodine or iodine forms, are discussed. It is not intended by this discussion either to endorse the use of, or disqualify any of the evaluated adsorbents, but to point out important parameters both for the adsorbents and for the test methods by which they were evaluated.

Amine impregnated carbons are excluded from the discussion because they function by a different process than iodine-impregnated carbons.

Except for some data on the physical properties of several carbons, there are no original new data presented below, except for showing relationships of the data not evaluated by the original authors. Wherever the legend on figures requires further qualification or explanation, additional data are presented in the notes.

Carbon Properties

The basic properties of the carbons discussed in this evaluation are listed in Table 1. Additional properties of carbon are described in detail in the discussion portion of this section.

Test Procedures and Results

ORNL Test Equipment and Procedures I (Work reported primarily by and Messr. R. E. Adams and R. D. Ackley)

Test equipment for the low temperature studies (25-100°C) is described in ORNL-4040 (Ref. 20). The activated carbon sample holder is a simple, horizontal, one-inch I.D. glass tube, where the carbon is held in place between woven, stainless steel screens. The carbon sample is gravity-packed into successive 1/2, 1/2, and 1 inch deep beds. Air, prehumidified air, and $CH_3{}^{131}I$ - air mixture are introduced into a heated zone where the carbon beds are located. Close examination of this equipment suggests a number of characteristics which could affect the test results. A "wall effect" could be encountered since there was no flanging around the perimeter of the bed. Also, should slight settling of the bed occur during test, bypass leakage would result, leading to low efficiencies. There is a possibility that the air stream entering the carbon was at a slightly lower temperature than the carbon bed, which could deliver moisture droplets to the bed. There were no drains between nor after the test beds. Should tests be conducted with an occurrence of both bed settling and carbon water-logging, results of methyl iodide decontamination efficiency would be extraordinarily low, owing to combined bypass leakage and reduced residence time, if interstitial flow areas were blocked with water.

Methyl iodide, labelled with $CH_3{}^{131}I$ was introduced over a period of approximately 2 hours after which the flow of air was continued for an additional period of approximately 4 hours. At the end of the test, the setup was disassembled and the amounts of ^{131}I radioactivity in the test beds and the downstream sections were determined by means of gamma scintillation spectrometry. It is not known if the relative humidity was readjusted after the $CH_3{}^{131}I$ introduction was stopped.

The data obtained using this test apparatus are presented on Figures 2, 3, 4 and 5.

In some of the tests, at a reported 100 percent relative humidity (RH), bulk phase condensation of water was observed in the first 1/2 inch bed. As will be discussed later, a carbon bed in equilibrium with air at 100% RH will not exhibit bulk phase condensation. Thus, the control of moisture content for these tests was apparently very poor, leading to erroneous conditions during the evaluation of methyl iodide decontamination.

The test equipment used for the high temperature steam air runs (M8 - 144°C) is also described ORNL-4040. The equipment is similar to that used for the low temperature studies. The authors state that the test beds were not always pre-equilibrated with respect to moisture content prior to methyl iodide introduction; however, the rate of steam flow was such that the carbon would have been eqiulibrated in a period of time that was short relative to the time corresponding to the methyl iodide injection.

Temperatures were monitored by thermocouples. It is not known or reported if there was any significant variation between the inlet gas temperature and the carbon bed holder temperature. The lack of pre-equilibration could have caused temporary temperature variations due to heat of adsorption of H_2O.

Moisture separators and HEPA filters were not used upstream of the carbon filters to eliminate any entrained water droplets from the inlet gas stream.

Data obtained in the test apparatus are shown in Figures 6 through 12.

Based on the results in some areas, water loadings 3 times those obtained at 100% RH, from water adsorption isotherms, were observed after the completion of the tests, indicating insufficient control of temperature and/or RH in the test equipment.

ORNL Test Equipment and Procedures II (Work reported primarily by G. W. Parker for LOFT support work.)

The test equipment is described in CONF - 660904 (p. 201-212) Ref. 18.

The activated carbon was placed in a segmented bed consisting of 1-cm or 2-cm sections. These were held vertically with "O" ring gasketing to prevent leakage. The beds were not baffled around the edge to eliminate possible wall effect. Possible settling was no problem because the beds were held in a vertical tube.

The temperature of the carbon beds was maintained at 75°C, and the relative humidity was maintained at 100% by bubbling air through water in a heated container. A water trap was installed downstream of the carbon beds but upstream of the condenser and the back-up carbon beds. Two different carbon cartridges were used 1 cm and 2 cm deep, but the volume was the same 4 cm^3 (approximately 1.6 g of carbon) to obtain equal residence times.

The "wall effect" i.e. the bypass caused by the packing voids between the smooth glass wall and the carbon grains is generally observed at tube I.D. - maximum grain diameter ratios below 10:1. Thus, it is expected that with the MSA 85851 max. grain diameter of 2.38 mm, some by pass was obtained in this series of tests.

Air at 75°C and 100% RH was passed through the cartridges for 1/2 hour prior to the addition of methyl iodide. It was found that the moisture content of the carbon varied between 35 and 47% showing that the beds were not at equilibrium with water at the beginning of the methyl iodide introduction.

The $CH_3{}^{131}I$ tagged $CH_3{}^{127}I$ loading was established to obtain a 1/4 hour loading period*. After loading, the cartridges were subjected to a 4-hour sweep by air at 75°C and 100% RH.

The moisture content of the cartridges after the test runs varied between 85 and 19% and averaged between 67 and 31% decreasing with direction of flow.

Due to the fact that relative humidity was not a variable the data obtained from this series of tests were related to the residence time. $CH_3{}^{131}I$ decontamination efficiencies are shown in Figure 16. Long range retention of ^{131}I was also studied in the same equipment and will be discussed later.

UKAEA Test Equipment and Procedures (Work reported primarily by D.A. Collins and coworkers).

No detailed description of the carbon sample holder is available; however, bed depths of 3" were reported at flow rate of 11.6 liters/minute. The carbon was dried first than equilibrated with water (to 98 - 100% RH) for 16 hours. From the test description (i.e. using a series of bubblers with water at a few degrees above air temperature and then bringing the air stream to room temperature to remove excess water) the air stream is presumed to be at 100% RH. The weight gain due to water adsorption is also very near the data obtained from water adsorption isotherms.

After the bed was brought to equilibirum with water, the $CH_3{}^{127}I$ labelled with ^{131}I was injected into the air stream for a 10 - 15 minute duration. The methyl iodide loading for standard tests was at 100 μg/g carbon. After CH_3I loading the humid air flow was maintained for at least four hours.

The air supply was filtered before entering the humidifier and the humid air passed through a demister and absolute filter before entering the carbon bed.

---

* Several tests were performed using a 20 hours loading period; however, in these runs the carbon bed was heated to several °C above the gas stream temperature.

Additional variations were performed by altering residence time, humidity, methyl iodide mass and methyl iodide loading time. These procedures are described in TRG 1300(W) Ref. 15. Data obtained in this equipment are shown in Figures 17 and 18.

Karlsruhe Nuclear Research Center Equipment and Test Procedure (Work reported by Mr. J. G. Wilhelm.)

The test equipment is described in paper SM-110/60 presented at the IAEA Symposium on Operating and Developmental Experience in the Treatment of Airborne Radioactive Wastes, Ref. 23.

The sweep gas enters the equipment through a particulate filter and the flow is measured, mixed with steam and transported to a double-walled, thin-coil cooler. In this cooler the dew point can be controlled to ±0.1°C. The carbon sample is kept in a water bath and the test stream is introduced to the carbon in a thermostat tube which is also in the water bath. In the thermostat tube the gas temperature is controlled within ±0.03°C. The gas enters to the test carbon through a deep glass wool filter.

The relative humidity in the apparatus can be measured both by psychrometric methods and from the volume of the condensate. Tests were run at 100% relative humidity without condensation in the test beds.

Times required to equilibrate the carbons tested with water are determined experimentally in the same apparatus. There is generally 20 hours prehumidification.

The $CH_3{}^{131}I$ - $CH_3{}^{127}I$ mixture is loaded onto the carbon for an additional 20 hours duration in the humid air.

After the methyl iodide loading the humid air stream flow is maintained for an additional 2 hours.

$CH_3{}^{131}I$ and $CH_3{}^{127}I$ ratios were varied up to 1±0.2 Ci/g of carbon. Figures 19 - 21 represent data obtained in this test apparatus.

Westinghouse Test Facility (Work performed for the Connecticut Yankee Atomic Power Company)

Description of the test equipment and procedures used were reported in CYAP-101 Ref. 24.

This work is an engineering evaluation test performed on modular units of the Connecticut Yankee nuclear reactor reactor air filtration system.

The carbon filter units were drawer shape having a twin 26 inch x 24 inch face, 2 inch deep bed. Air flow entered this unit both from the top and from the bottom and exited at the front. All screen surfaces where "wall effect" bypass flow could occur were blanketed with a strip of nonperforated metal.

The total loop volume for the recirculating system was 3.68 m^3. The temperature and relative humidity control was achieved by the injection of superheated steam and by the use of loop duct wall heaters. When it was required, air was also added to the loop to make up for losses caused by sampling and leakage. The temperature was kept at 127°C where the steam saturation pressure is 35.8 psia, air at 127°C where the steam saturation pressure is 35.8 psia, air at 127°C supplied a pressure of 19.7 psia, and, thus; loop pressure was maintained between 35 and 43 psig. Relative humidity was indicated by wet and dry bulb thermometers just upstream of the carbon beds. Recorded data indicate that 100% RH was maintained after the initial test.

Gas stream velocity was maintained a 83 FPM through the carbon bed and the loop flow was 625 CFM at test conditions. Methyl iodide was added to obtain loop air concentrations of ∿10 and ∿500 mg/m^3. Tracer methyl iodide was added to obtain approximately 8000 dpm/liter concentration upstream of the filter.

The loop assembly is shown on Figure #22.

Description of Main Loop

A. Component Description

| The loop assembly is shown in Figure 22 and consists of all the following items:

1. The gas circulating fan is the centrifugal type rated for handling 1000 cfm of water saturated air at 90 psig and 325°F. It is equipped with a leak-proof water cooled shaft seal.

2. Steam injected into the loop through a 304 SS spray nozzle header, is the main source of high temperature water vapor to saturate the air. The steam, supplied by a portable steam generator, is controlled manually by valves.

3. A finned-tube steam heating coil is provided to preheat the air, and assist in maintaining the desired test temperature. Steam (250 psig max.), supplied by the portable steam generator, is manually controlled by valves. The finned tubing is 5/8" x 0.049" wall 304 SS tubing on which 304 SS fins have been attached.

4. A water-cooled cooling coil, similar to the heating coil, is included for additional regulation of the test atmosphere conditions. It is identical to the heating coil, and is, in fact, interchangeable with the heating unit. The cooling water is also manually controlled.

5. The ductwork consists primarily of nominal 26" x 26" square duct. The square duct is fabricated from 3/8" 304 SS plate, longitudinally and transversely reinforced with 1/2" square bar stock welded over the entire duct exterior so as to form flat rectangular panels 8" wide x 12" long.

The discharge and suction sections of the ductwork are 8" sch. 5 welded pipe and fittings; the flanges are standard 150 psi units. Four banks of electric strip heaters (24 KW total) are mounted on the exterior surfaces of the square ducting to aid in maintaining isothermal test conditions. The entire duct system is insulated with 2" thick fiberglass board.

Traps are located at low points in the ductwork; specifically upstream and downstream of the moisture separator and test filter. All condensate is collected through individual lines into separate collection reservoirs for inventory and/or disposal.

6. A 250 psig electrically heated (48 KW) portable steam generator provides:

   a. Steam to the heating coil.
   b. Steam for saturating the air.
   c. Auxiliary pressurizing fluid for manual control of the system pressure.

7. A 150 psig Gardner-Denver air compressor with a 30 gallon receiver provides air for system use.

8. The charcoal test filter is located in the square duct just upstream from the blower. A drawing of a typical filter is presented in Figure 23. Charcoal filters from three different manufacturers were used during these tests, Mine Safety Appliances, Barnebey-Cheney, and American Air Filter.

9. A Connecticut-Yankee prototype moisture separator and Connecticut-Yankee prototype particulate filter were placed in the square duct section downstream from the steam injection line.

B. Instrumentation Description

1) The air flow is measured by a differential pressure dial indicator in conjunction with an in-line orifice plate.

2) Test filter differential pressure is measured by a differential pressure dial indicator located adjacent to the filter.

3) Temperature measurement. (1) Wet and dry bulb temperatures were measured before the test filter using a suitable gas-filled thermal system consisting of two sensing bulbs connected to a temperature recorder. (2) A 24-point temperature recorder and iron-constantan thermocouples were used to measure duct wall temperatures, temperature downstream of the heating and cooling coils, and to provide temperature information for the Chemical Injection-Analysis System.

4) System pressure is measured by means of direct-connected Bourdon tube pressure gages.

The MSA filters contained MSA 85851 Carbon. The BC filters contained BC 727 carbon. The AAF filters contained noniodized carbon; thus the results obtained in series designated CY-4-AAF are disregarded for the purpose of this study.

Loop drain water, loop smears, air samples as well as the moisture separator and particulate filters segments were tested for activity in addition to the carbon used at the end of each test. The carbon was also tested for moisture content.

The testing was conducted for 11-24 hours under the described conditions.

There was a small loss of CH_3I in the system requiring addition of stable CH_3I makeup to the system. Although the exact means of the removal process were not found it was observed that the loss was proportional to the rate of steam loss from the system. It was also shown that the manner of removal was not by physical adsorption on the carbon.

Radioactivity removal efficiency measurements made throughout the period of testing at the simulated accident conditions were expressed in two ways, viz., "instantaneous" and integrated". These were defined as follows:

$$\text{Instantaneous Efficiency: } \%E = 100 \quad \left(1 - \frac{A_{out}}{A_{in}}\right)$$

Where A is the activity of the loop air due to $CH_3{}^{131}I$ at the upstream (in) and downstream (out) faces of the carbon bed. The technique used for this measurement consisted of collecting air stream samples during a 10 minute interval from both upstream and downstream locations near the carbon filter. The samples collected were subsequently analyzed for total activity content and thus represent a sum of the activity contained in the air sample. Preceding the collection of the 10 minute samples, high specific activity $CH_3{}^{131}I$ injection flow into the loop was begun and this flow maintained for 5 minutes before, and throughout the sampling period. Tracer $CH_3{}^{131}I$ was injected at a point in the loop well upstream of the carbon bed to insure that mixing was complete before reaching the sample points and carbon bed.

$$\text{Integrated Efficiency: } \%E = 100 \ \frac{\Sigma A \text{ (on carbon)}}{\Sigma A \text{ (all assay samples)}}$$

Following a test, the carbon was removed from the filter housing and assayed for contained ^{131}I. This value, compared to the total ^{131}I activity found elsewhere in the loop water samples, smears, moisture separator pads, HEPA filter, etc., represents an overall, integrated, ^{131}I removal efficiency.

The results of four tests with iodine impregnated carbon are summarized below:

FIGURE 24

Test	RH%	Efficiency Range (instantaneous)	Carbon H_2O Content	
			Top	Bottom
CY-1-MSA	92.0	86-95	37.2	28.2(c)
CY-2-MSA	95	75-90(a)	42.0	44.3
CY-3-BC	100	70-95(b)(a)	47.5	49.2
CY-5-MSA	100	61-91(a)	28.6	36.8

(a) The low values were obtained immediately after water was sprayed onto the carbon filters, thereafter efficiency increased again.

(b) One reading of 23.3% was obtained, however the two neighboring efficiencies were 95.1 and 77.00; thus this number is not used here.

(c) Data indicate the possibility the filter was turned over at one stage or another.

It is shown that direct water spray onto the carbon beds reduces the efficiency from above 90% to about 60%; however, within one hour the instantaneous efficiency recovered to 78-79% again.

Tracer inventory following the completion of each test showed only trace amounts of activity outside the carbon filter. It is significant to point out that even in the one test series CY-4-AAF which contained a noniodized impregnated carbon, and where the instantaneous efficiencies were from 18-53%, the final tracer inventory showed essentially all activity on the carbon filters, thus showing the considerably improved integrated efficiency in recirculating systems.

EVALUATION OF THE RESULTS

In order to evaluate the results obtained in the various experiments described above, the structural properties of activated carbons and their water adsorption properties should be reviewed.

Commercial activated carbons are characterized by a polymode volume distribution of pores and contain various types of pores. The smallest pores are generally referred to as micropores in size commensurate with the size of the adsorbed molecules. Their volume expresses the limiting volume of the adsorption space, because the filling of the micropore volume in vapor adsorption results from the merging of the adsorption layers on the opposite sides of the pores.

Activated carbons also contain transitional pores which are larger than the micropores. Where the effective radii of these pores are in the range of tens and hundreds of Angstroms, capillary condensation of vapors can occur in these pores at high relative pressures. The largest pores are called macropores having radii in the range of thousands and tens of thousands of Angstroms. There pores play the part of transport arteries making the internal structure of the carbon particles accessible for the molecules being adsorbed.

In general, the specific micropore surface is of the order of 500-1500 m^2/g, in tens of m^2/g for the transitional pores, and a few m^2/g for the macropores.

It is also important to recognize the basic carbon types, i.e., reconstituted and natural grain. Nonreconstituted activated carbons, such as coconut shell, have very large micropore volumes but very little macropore volumes. The very highly adsorptive coconut carbons may contain 0.9-0.95 ml/g micropore volume while their macropore volume is not higher than 0.15-0.20 ml/g. Reconstituted carbons made from powdered carbonaceous materials and binders when activated to very highly adsorptive levels may contain 0.9-1.0 ml/g micropore volume, while these carbons can have a macropore volume up to 0.7 ml/g.

The carbon discussed in this paper with the exception of the Norit RCX and the Sutcliff-Speakman 207B carbons are natural grain coconut shell carbons. The RCX and 207B have an approximate 0.3 ml/g macropore volume.

The pore volume distribution of the micro and intermediate pores for NACAR G601 is shown in Figure 25. The pore volume distribution of the MSA 85851 and the BC727 carbons is nearly identical to the G601.

The water adsorption properties of activated carbons may be described in the following manner: in the region of low equilibrium water vapor pressures (as relative humidity) the adsorption is due basically to the formation of hydrogen bonds between the water molecules and the primary adsorption centers, which are mostly surface oxides. The adsorbed water molecules represent secondary adsorption centers, which can retain other molecules due to hydrogen bonds at increasing water vapor partial pressures. As a result, dimeric complexes are formed with the water molecules at the primary adsorption centers on the carbon surface. With further rise in pressure, the probability of adsorption increases because of the rise in the number of the secondary adsorption centers. The steep rise in the water adsorption isotherm in the region of medium relative pressures (50-60% RH) is caused by the appearance and growth of dimeric islets formed by molecules of water associated as a result of hydrogen bonding. The fusion of these islets leads to the formation of the water monomolecular layer on the carbon surface. The further increase in relative pressure of water vapor causes polymolecular adsorption and possibly capillary condensation. However, only filling of the micropores and intermediate pores can be expected.

It is also important to note that physical adsorption is accompanied by a decrease in the free energy of the system. The process involves loss of degrees of freedom; thus, it is always exothermic. The adsorption of water on activated carbon, therefore, is an exothermic process. In Figure 26 the isosteric heat of adsorption of water on activated carbon is shown at various temperatures.

FIGURE 26

Temp. (°C)	Q_{iso} (cal/mole)
10	10,000
40	9,300
80	8,300
128	7,200
187	5,200

As it can be seen the heat of adsorption is somewhat less than the heat of liquification at identical temperatures; however, it is still significant.

In Figure 27 a portion of the water absorption isotherm for 207B carbon is shown. The curve shows the typical "S" shape. In Figure 28 the water adsorption capacity at 100% RH and 100°C is shown versus surface area (this is also related to pore volume) of the carbons. A typical water adsorption rate curve is shown in Figure 29 at 100% relative humidity and 31.2°C. The rate of water adsorption will be higher at elevated temperatures because of the increased rate of diffusion.

It is evident that there is a large variation in the control of relative humidity in the various experimental apparata used in the $CH_3{}^{131}I$ removal studies, which also influences the observed removal efficiencies.

It is reiterated here that the effect of relative humidity, on a proportional basis, is similar, regardless of temperaure. Thus, if at 25°C at a particular relative humidity, a certain water content corresponds to adsorption in certain specific pore sizes, a similar relationship exists at a higher temperature but the extent of water adsorbed will be less. At 125°C at all relative humidities, there will be less water adsorbed on the carbon surface than at 25°C. The shape of the water adsorption isotherm does not change significantly in the high relative humidity range with increasing temperature.(28)

There are significantly more data available for the $CH_3{}^{131}I$ removal in the temperature range below 100°C than at higher temperatures. Also, cross checks are available for carbons from several laboratories in the low temperature range.

It is fairly well known that the primary process by which iodine impregnated carbons remove ^{131}I from $CH_3{}^{131}I$ is by isotopic exchange. However, in some cases, very low levels of CH_3I adsorption (only at low temperatures, $<50°C$) or some catalytic decomposition of the $CH_3{}^{131}I$ (forming a strongly adsorbed form of iodine) is also indicated. Figure 33 shows physical adsorption at 100% RH and 24°C with various bed depths of unimpregnated carbons. However, the carbon used in this experiment contains some alkali ash, but the effect of this constituent is not known. Figure 31 shows calculated and measured $CH_3{}^{131}I$ penetration for KI impregnated carbons if the removal process was solely by isotope exchange. Better correlation is obtained between theoretical and measured exchange rates when the impregnate is I_2 or KI_3 $(KI + I_2)$.

The ORNL I data show the largest spread in $Ch_3{}^{131}I$ removal efficiencies at high humidity. In some cases, visual bulk phase condensation occurred in the carbon bed showing that the inlet stream was supersaturated. The extent of supersaturation can be seen when the observed efficiencies are compared with the data obtained by Collins and shown on Figure 17 indicating removal efficiencies both below and above the 100% RH water loading. It is important to note that to observe the wetting of the carbon bed, even the very large macropores have to be filled with water.

However, when careful control was exercised and bulk phase condensation did not take place (Figure 5 for ORNL, Figure 17 for UKAEA, Figure 19 for Karlsruhe) relatively good agreement can be observed between the various laboratories.

In the case of the high temperature runs, the insufficient control of relative humidity is even more evident. Unfortunately, the effect of condensation and subsequent water build up in the horizontal, 1-inch ID beds of ORNL iodine compounds itself by increasing the velocity through the unblocked part of the bed. The water had no means for drainage.

The water loadings obtained at very near 100% RH were up to 150% of the carbon weight. Knowing that at 100% RH, the higher the temperature, the less water the carbon will adsorb, and having water adsorption data on these carbons at 100% RH from various sources, the fact that the inlet gas stream was supersaturated is evident.

Condensed water in the carbon bed will certainly reduce the efficiency of the system, particularly if the water cannot drain from the bed. Collins (15) observed a drop in efficiency from 99.98% to 60% when water was condensed on purpose in the bed. Subsequent efficiency of the carbon after the RH was lowered to 100% was however 99.84%. In the same work, it was shown that while condensation in the bed lowered the subsequent 100% RH efficiency of a 207B/0.5% KI carbon bed from 99.98 to 99.86, the efficiency of a 207B/5%KI bed did not change after the condensation treatment. Thus, if for any reason, condensation would take place in a carbon bed, its instantaneous efficiency could be lower. However the efficiency is recovered after the water is removed from the beds. This phenomenon was also confirmed by the CYAP tests. Parker(18) also performed leaching tests on carbon loaded with 28 μg/g methyl iodide at 95°C on shallow beds where water was condensing in the carbon beds. It was found that some activity was removed from the bed after 2 hours. However, the iodine removed was not in organic form, but HI, and not found in the back-up carbon beds, but in the condensate.

Thus, if severe long-period condensation would take place in the carbon beds after all the $CH_3{}^{131}I$ was exchanged and the carbon contained all the activity, any released form of iodine would not be in a gaseous product.

The high temperature steam-air runs performed by ORNL used relative humidity values obtained from the average carbon temperature, total pressure, and steam-air flow rates. It was assumed that the inlet air-steam temperature was at the same temperature as the carbon bed. In addition, the possibility of forming water droplets in the gas stream when introducing the air to the steam existed and no facilities were made to remove entrained moisture.

Based on the water loading of the carbons at the end of the runs, it can be shown that particularly in the 95 - 100% RH range the qualitative control of relative humidity was not maintained. In some cases, particularly those showing the lowest efficiencies (the 100% RH values on Figure 8) even the calculated values were shown to be above 100% RH but they were reported to be at 100% RH (p. 12, ORNL-4180).

When plotting data for 3 similar carbons MSA 85851, BC 727 and G 601, shown on Figure 15, the data, excluding the confirmed supersaturation points and the questionable RH points, appear similar to the curve obtained for the low temperature range. This can be expected since at the higher temperature the carbon will hold less water and the $CH_3{}^{131}I$ diffusion will be faster; thus, if anything, under carefully controlled conditions, better exchange values should be obtained at high temperatures than at low temperatures. The fact was confirmed for several carbons in the 90% RH range by the ORNL workers.

The most carefully controlled temperature and RH conditions were maintained by Wilhelm(23) who placed the carbon samples in a water bath with sufficient exchange surface ahead of the carbon bed to assure that the gas stream was of the same temperature as the carbon bed. When corrected for particle size differences, the data agree with those of other workers. The importance of particle size is very often overlooked. From the available data two particle size versus exchange efficiency curves were prepared. Figure 20 shows the various particle diameter pellets used by Wilhelm and Figure 18 shows 207B with 0.5% KI ground to various particle sizes versus exchange efficiency.

Wilhelm also measured exchanges efficiencies with various $CH_3{}^{131}I$ loadings while keeping the $CH_3{}^{127}I$ concentration constant. No significant difference in activity removal was found between the range of 3 ± 0.6 mCi/g carbon and 1 ± 0.2 Ci/p carbon loadings. (Figure 21)

Parker et. al(18) was first to observe the consequences of condensation in the carbon bed when used for isotope exchange at 100% RH. When careful control of RH was maintained good exchange efficiencies were obtained. In Figure 16 the effect of residence time versus exchange efficiency is shown for a 2" deep bed at 75°C. Parker also pointed out the important fact that at even equal residence times a deeper bed will have higher efficiency, thus the relationship between residence time and efficiency is not exactly linear if large differences in bed depth exist.

In the course of this discussion, several impregnation effects were mentioned. Figures 32 - 34 are presented to show these relationships. Of course, Figure 31 also gives some insight to the effect of impregnate quantity.

The results discussed until now related to single pass efficiency. There are very few data available outside CYAP 101 (24) on recirculating system $CH_3{}^{131}I$ removal efficiencies. The only other data are in ORNL 4071 (29) and they are not extensive. The ORNL data showed a partition factor after 560 minutes recirculation of 95% on the carbon and 5% on the gas stream.

Due to the fact that the CYAP tests were on an engineering scale and the carbon was tortured by water deluges during the testing, the large range efficiencies of the carbon tested are not readily apparent. The most significant result of the CYAP test is that at the end of the tests almost all of the introduced activity was found on the carbon filters. This was true even in the case of the one non-iodized carbon where the instantaneous (as close to single pass as one can get in a recirculating system) efficiencies were 18 - 53%.

Final water contents of carbons have the CYAP tests were recorded on a multiple sample point basis. The averages were shown in Figure 24. On first inspection, the water contents do not appear to be high enough for the 100% RH loading. However if these results are compared with the relative humidity maintained in the loop after the testing until the loop cooled down below 40°C, the results are more meaningful. As an example, the samples from run CY-5-MSA were in the loop for over 10 hours at considerably less than 100% RH and the CY-3-BC samples were under the same conditions for only about 4 hours.

This long-term exposure at low relative humidity undoubtedly effected removal of water from the carbon adsorbed during the test exposure at 100% RH. With this consideration, the water content data of Figure 24 is reasonable. Evidently during operation the moisture loading of the carbons was significantly higher. It would have been more meaningful although considerably more complicated if the carbon filters could have been removed immediately after the end of the test.

The CYAP tests show that in full scale filters where water can drain from the filters, flooding cannot be maintained. Instantaneous efficiencies immediately following water sprays were in the order of 60 - 70%. The lowest instantaneous efficiency caused by flooding recovers to 78 - 80% efficiency after one hour. When water was not sprayed onto the filters in the RH% range of 92 - 100 the instantaneous isotope exchange efficiencies were approximately 90%.

It is necessary here to look on a complete filter system and evaluate conditions which may exist in the filter system under accident conditions in relationship to flooding and/or RH. The carbon filters are preceded in reactor filter systems by moisture separators and particulate filters which remove entrained water from the gas stream. These filters have a very high efficiency for particulate water.(30, 31) Thus the possibility that any significant amount of entrained water would reach the carbon filters is highly unlikely.

Moreover, as discussed previously, the adsorption of water is an exothermic process leading to a temperature rise in the carbon which opposes moisture condensation - at conditions of less than 100% RH. This characteristic of water adsorption would apply during the initial phase of an accident, while the carbon beds were being raised to the accident temperature. Following this, there is no conceivable way the carbon bed can be at a temperature lower than that of the flowing air; i.e., condensation is not possible in the bed. In fact, if one considers the energy release of adsorbed fission products, the bed will be slightly superheated and its moisture content will correspond to that of less than 100% RH. Very little temperature rise can significantly lower the relative humidity, as, for example, a 0.5°C change results in a 1.6% change in RH, at 55 psia, 130°C.

It should also be emphasized again that water carried to the carbon bed, resulting in a water content in excess of the adsorption isotherm value, is an unstable condition which will become rectified as air flow continues. Interstitial water (flooding) in the carbon bed will be removed, if it occurs, through drainage enhanced by the air flow.

CONCLUSIONS

A careful analysis of available data on the performance of iodine impregnated carbons, the test methods used for these evaluations, and the appropriate properties of carbons, leads to the conclusion that this process is effective in the decontamination of methyl iodide. At the design conditions following the hypothetical reactor accident, the decontamination process is still effective in the 100% relative humidity environment, showing radioactivity removal efficiencies on the order of 70 percent or better per single pass of the air-steam vapor mixture. It is recognized that carbon beds can become temporarily flooded with water, which reduces the activity removal efficiency, but properly designed air handling systems, consisting of moisture separators and HEPA filters, will prevent water droplet carrythrough to the carbon bed. Moreover, were one to assume a mechanism whereby flooding could occur, a properly designed carbon filter bed and housing will permit the entrained water to drain and thereby restore the filter's efficiency for decontamination.

FIGURE 1

	NACAR(1) G601	MSA(2) 85851	MSA 24207	BC(3) 727	BC 239	PCB(4)	SS(5) 207	Norit(6) RCX
Raw Material	Coconut	Coconut	Coconut	Coconut	Coconut	Coconut	Coal	Peat
Surface Area (BET) m^2/g	1400	1400	900	1400	900	1000	1000	1000
	Impregnated					Unimpregnated		
Pore Volume (N_2) mls/g	0.9	0.9	0.6	0.9	0.6	0.6	0.6	0.6
Particle Size U.S.S. Sieve	10x16	8x16	8x16	8x16	10x16	12x30	8x16	(a) Approx. 20 mesh
Iodine Impregnation	Yes	Yes	Yes	Yes	Yes	(b)	(b)	(b)

(1) North American Carbon, Inc., Columbus, Ohio
(2) Mine Safety Appliances Co., Pittsburgh, Pa.
(3) Barneby-Cheney Co., Columbus, Ohio
(4) Pittsburgh Activated Carbon Co., Pittsburgh, Pa.
(5) Sutcliffe-Speakman, United Kingdom
(6) Norit, New York

(a) Extruded pellets, Diameter 0.8 mm/Length 2-3 mm
(b) These are base carbons. Impregnation type and quantity is listed with data.

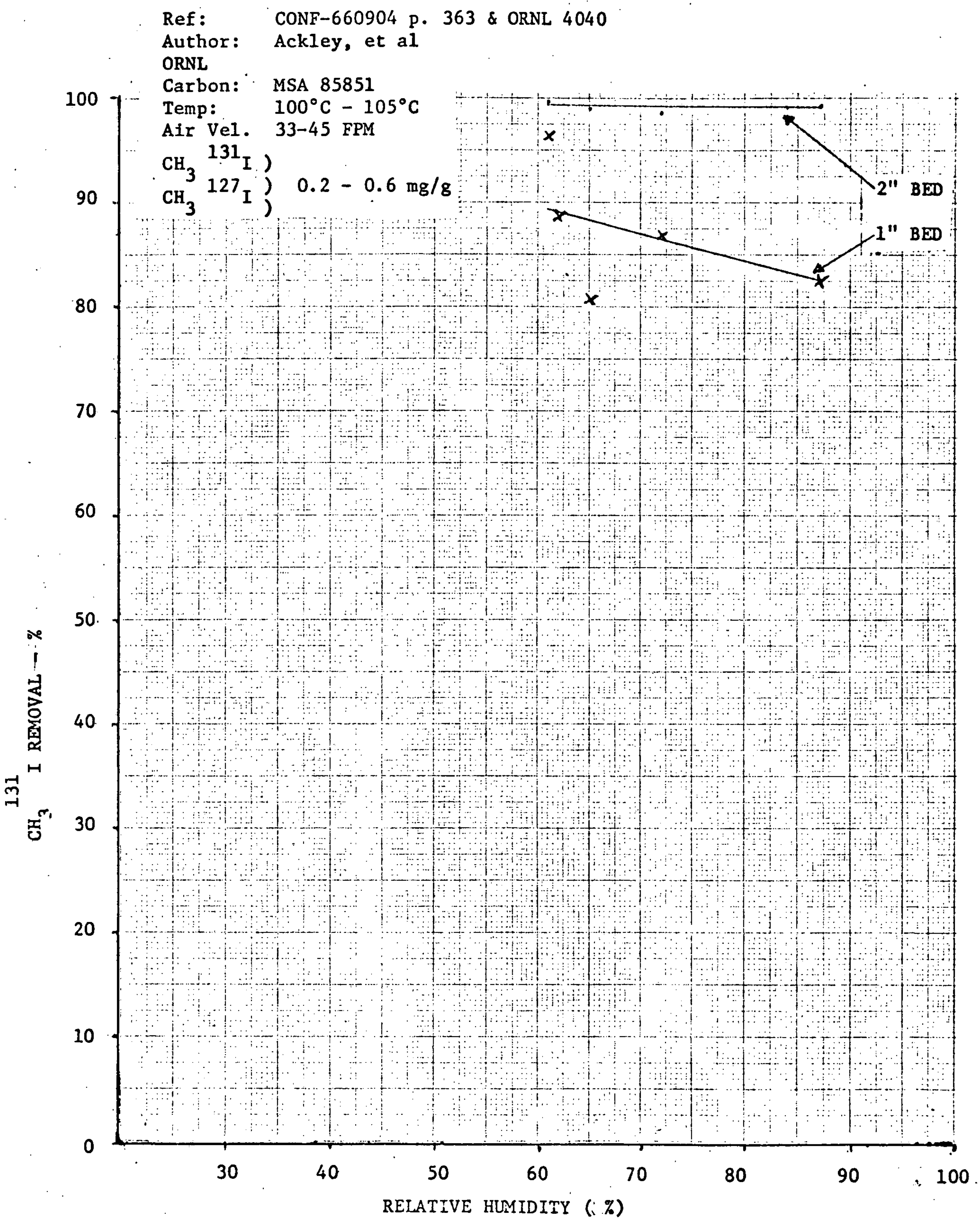
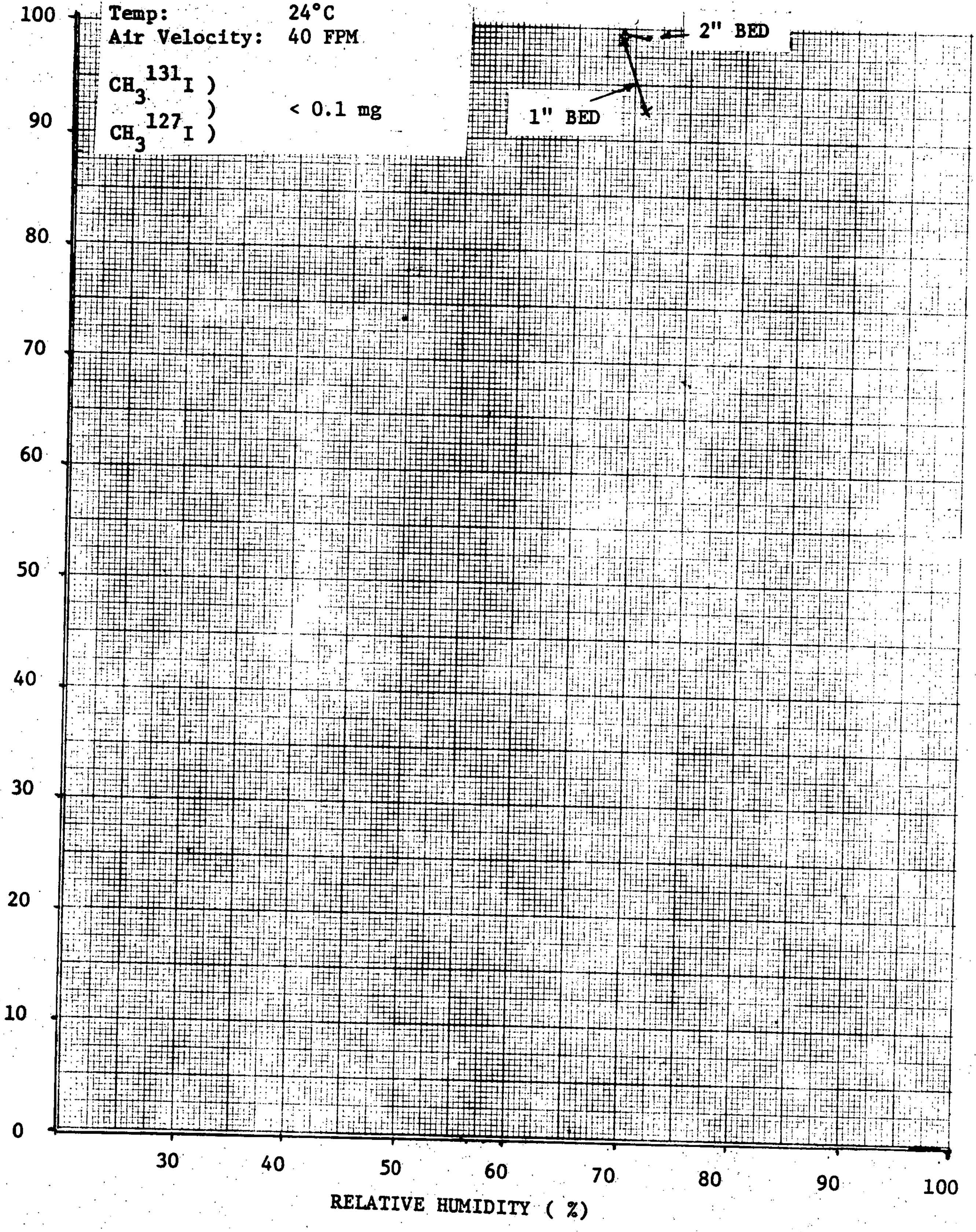

Ref: CONF-660904 p. 363 & ORNL 4040
Author: Ackley, et al
ORNL
Carbon: MSA 85851
Temp: 100°C - 105°C
Air Vel. 33-45 FPM
$CH_3{}^{131}I$)
$CH_3{}^{127}I$) 0.2 - 0.6 mg/g
)
2" BED
1" BED
100
90
80
70
60
50
40
30
20
10
0
30
40
50
60
70
80
90
100
$CH_3{}^{131}I$ REMOVAL — %
RELATIVE HUMIDITY (%)

FIGURE 2



Ref: ORNL-3915

Author: Adams & Ackley

ORNL

Carbon: MIA 85851

Temp: 24°C

Air Velocity: 40 FPM

$CH_3{}^{131}I$)
) < 0.1 mg
$CH_3{}^{127}I$)

FIGURE 3

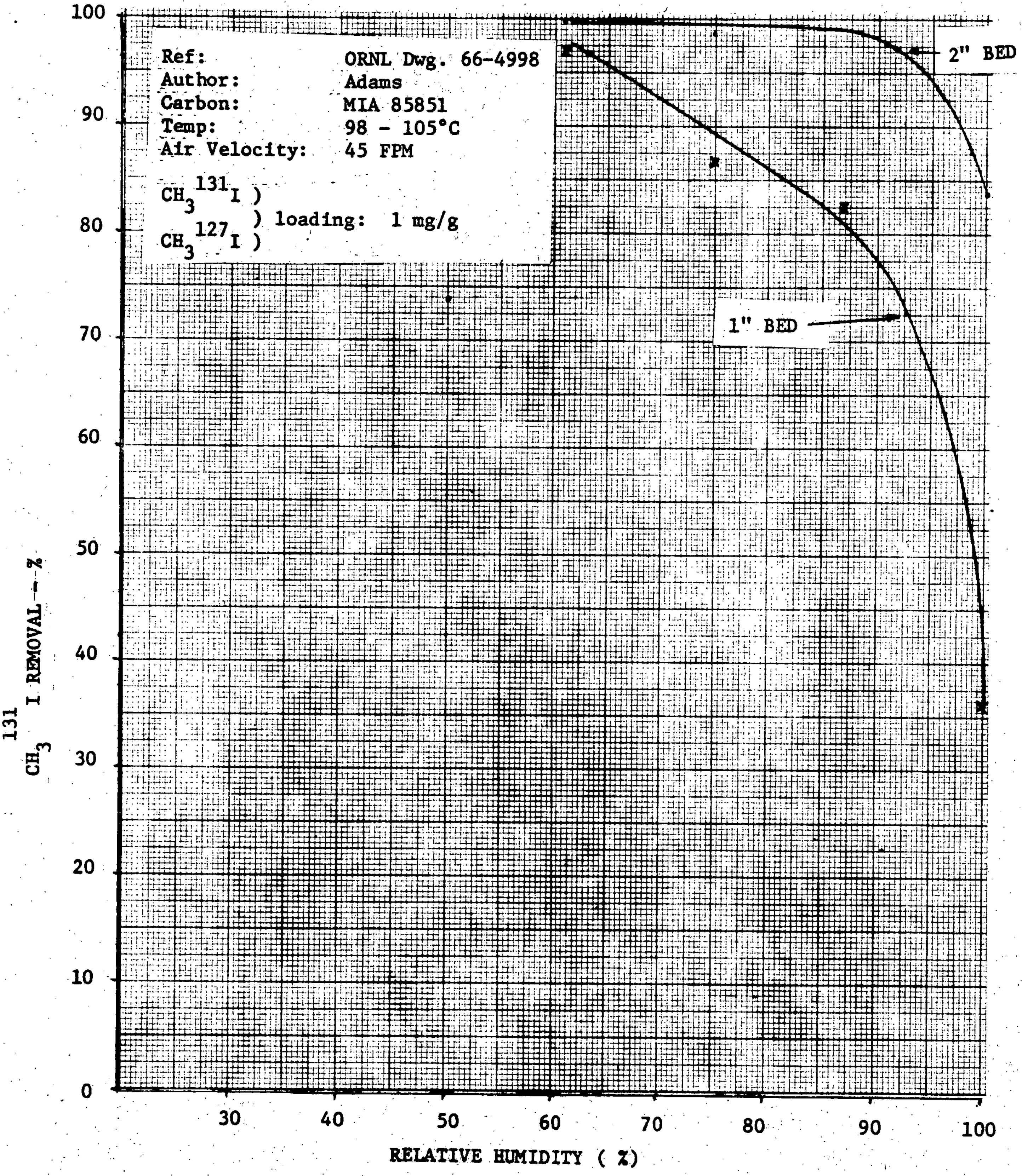
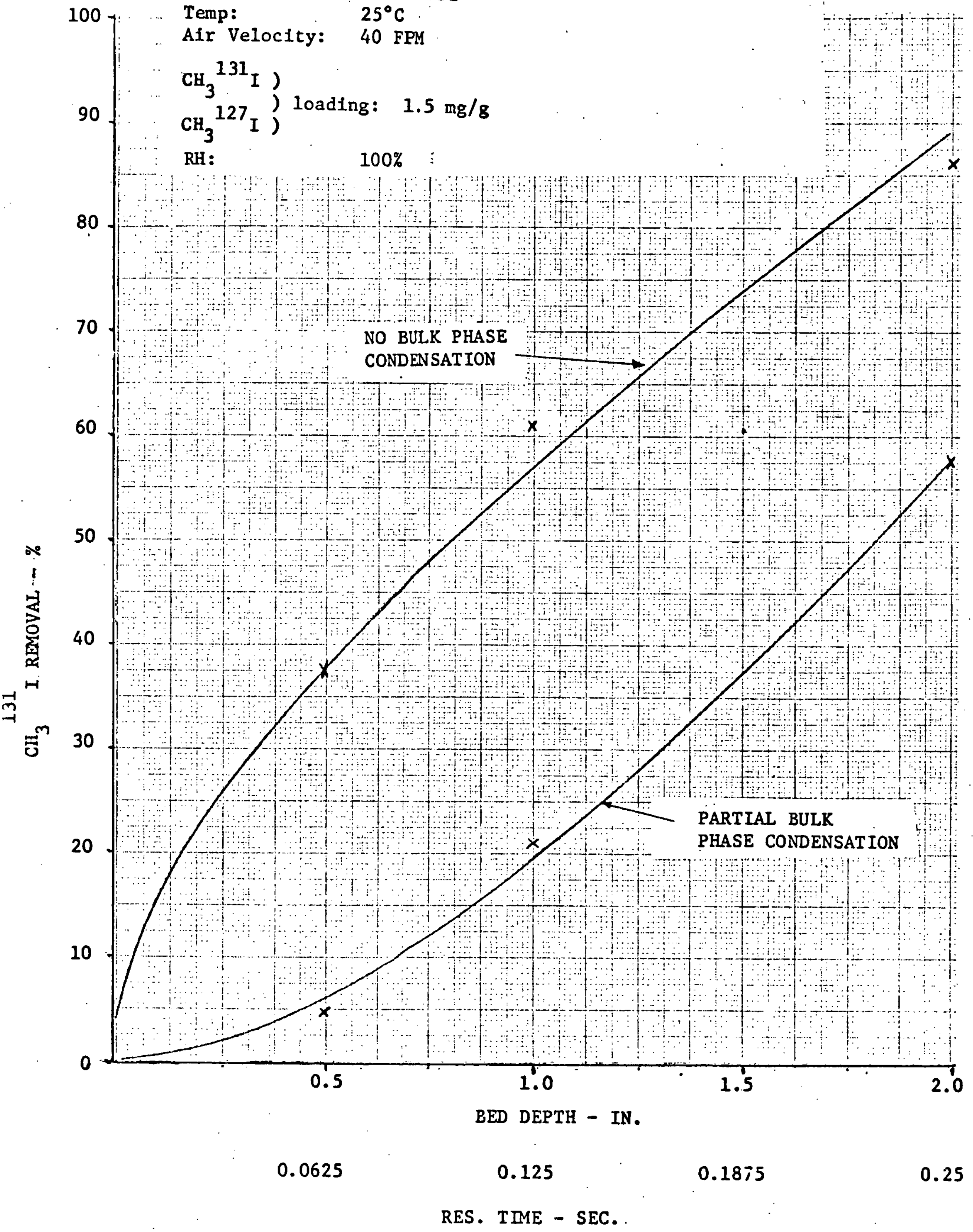

Ref: ORNL Dwg. 66-4998
Author: Adams
Carbon: MIA 85851
Temp: 98 - 105°C
Air Velocity: 45 FPM
$CH_3{}^{131}I$) loading: 1 mg/g
$CH_3{}^{127}I$)
2" BED
1" BED
$CH_3{}^{131}I$ REMOVAL — %
RELATIVE HUMIDITY (%)
0
10
20
30
40
50
60
70
80
90
100
30
40
50
60
70
80
90
100

FIGURE 4



Ref: Paper SM 110/37 IAEA - ORNL Dwg. 67-1216
Author: Adams, et al
ORNL
Carbon: MSA 85851
Temp: 25°C
Air Velocity: 40 FPM
$CH_3{}^{131}I$)
) loading: 1.5 mg/g
$CH_3{}^{127}I$)
RH: 100%

FIGURE 5

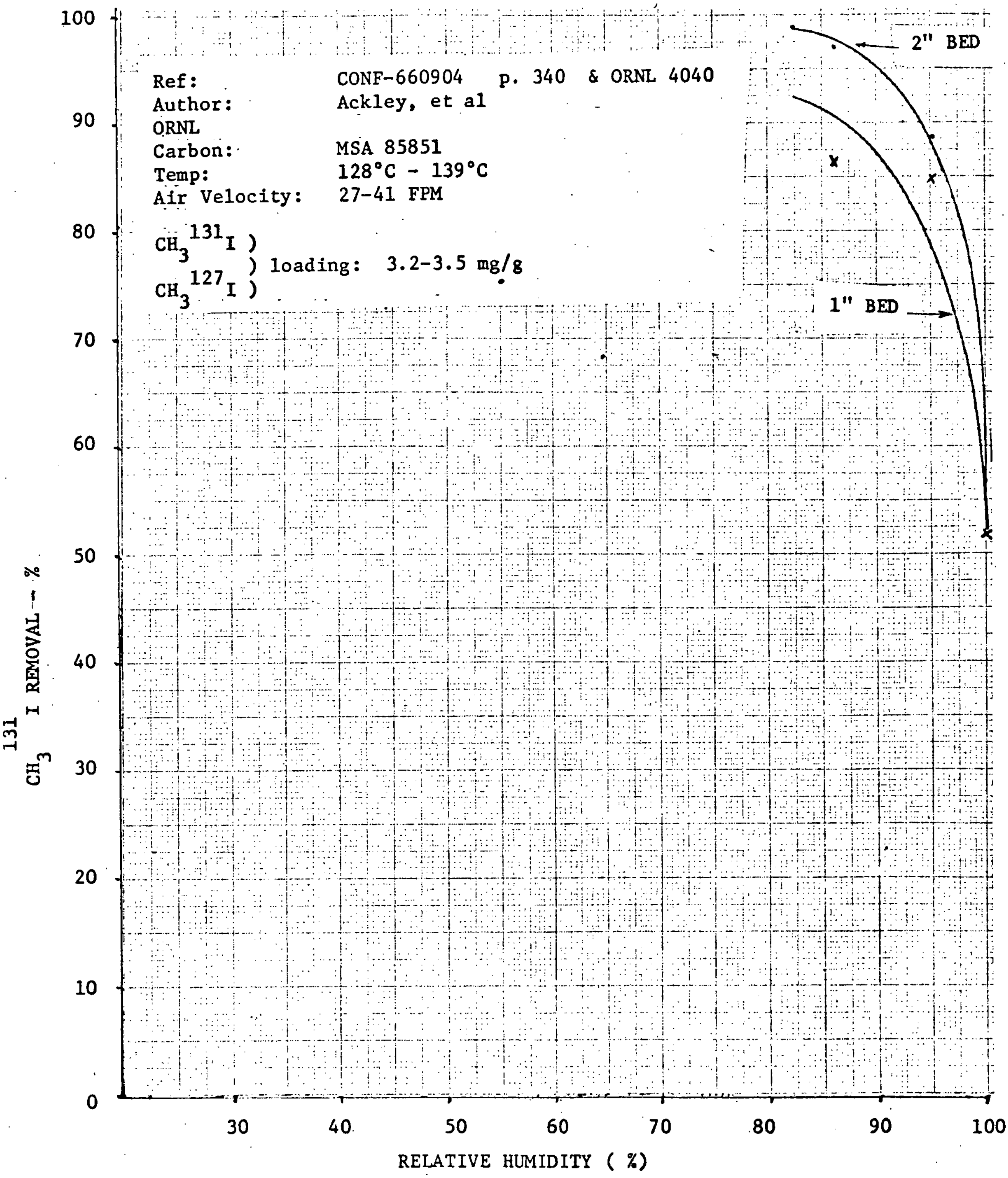
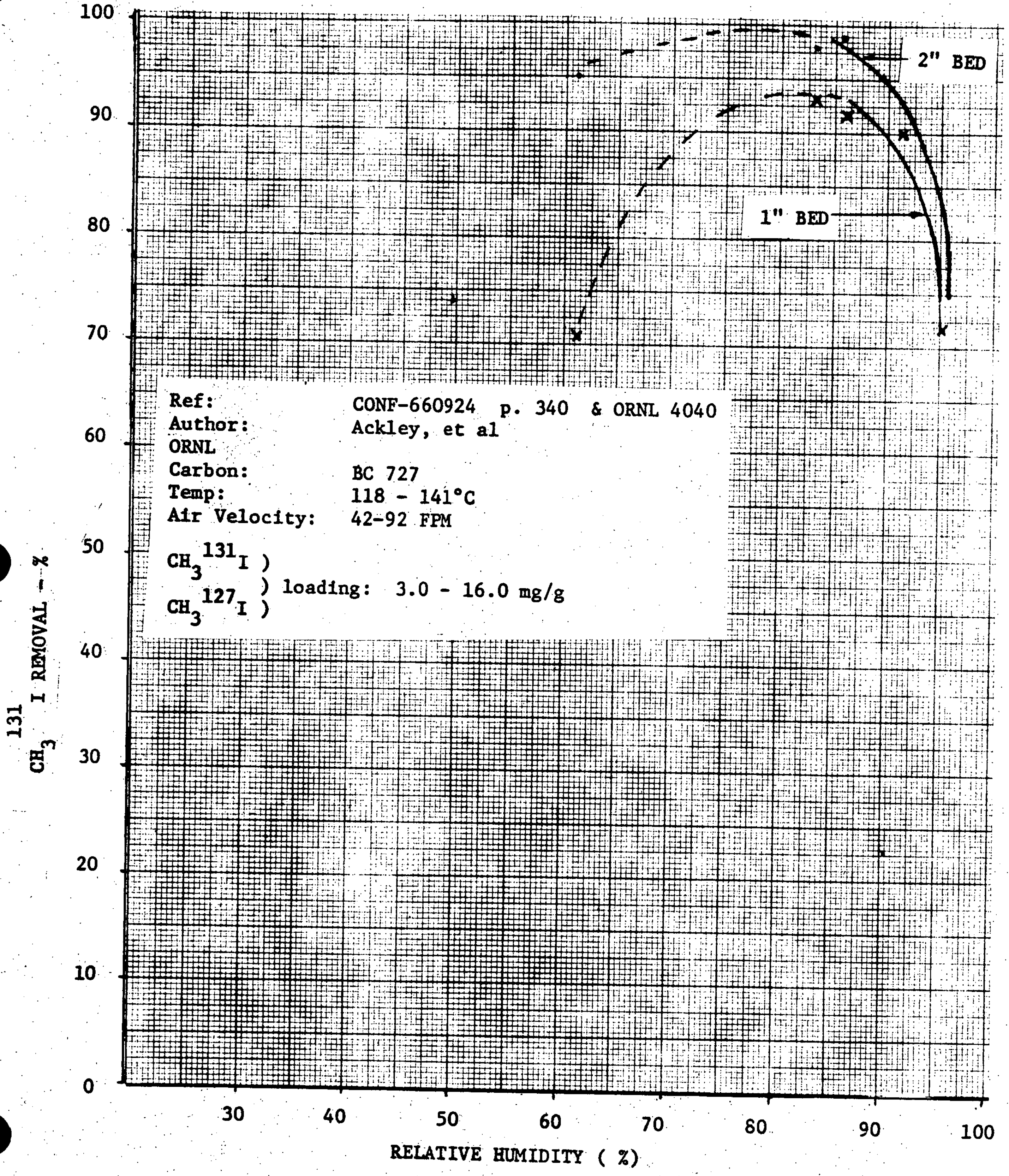

Ref: CONF-660904 p. 340 & ORNL 4040
Author: Ackley, et al
ORNL
Carbon: MSA 85851
Temp: 128°C - 139°C
Air Velocity: 27-41 FPM
$CH_3{}^{131}I$)
) loading: 3.2-3.5 mg/g
$CH_3{}^{127}I$)
2" BED
1" BED
$CH_3{}^{131}I$ REMOVAL – %
0
10
20
30
40
50
60
70
80
90
100
30
40
50
60
70
80
90
100
RELATIVE HUMIDITY (%)

FIGURE 6



Ref: CONF-660924 p. 340 & ORNL 4040
Author: Ackley, et al
ORNL
Carbon: BC 727
Temp: 118 - 141°C
Air Velocity: 42-92 FPM

$CH_3{}^{131}I$)
) loading: 3.0 - 16.0 mg/g
$CH_3{}^{127}I$)

FIGURE 7

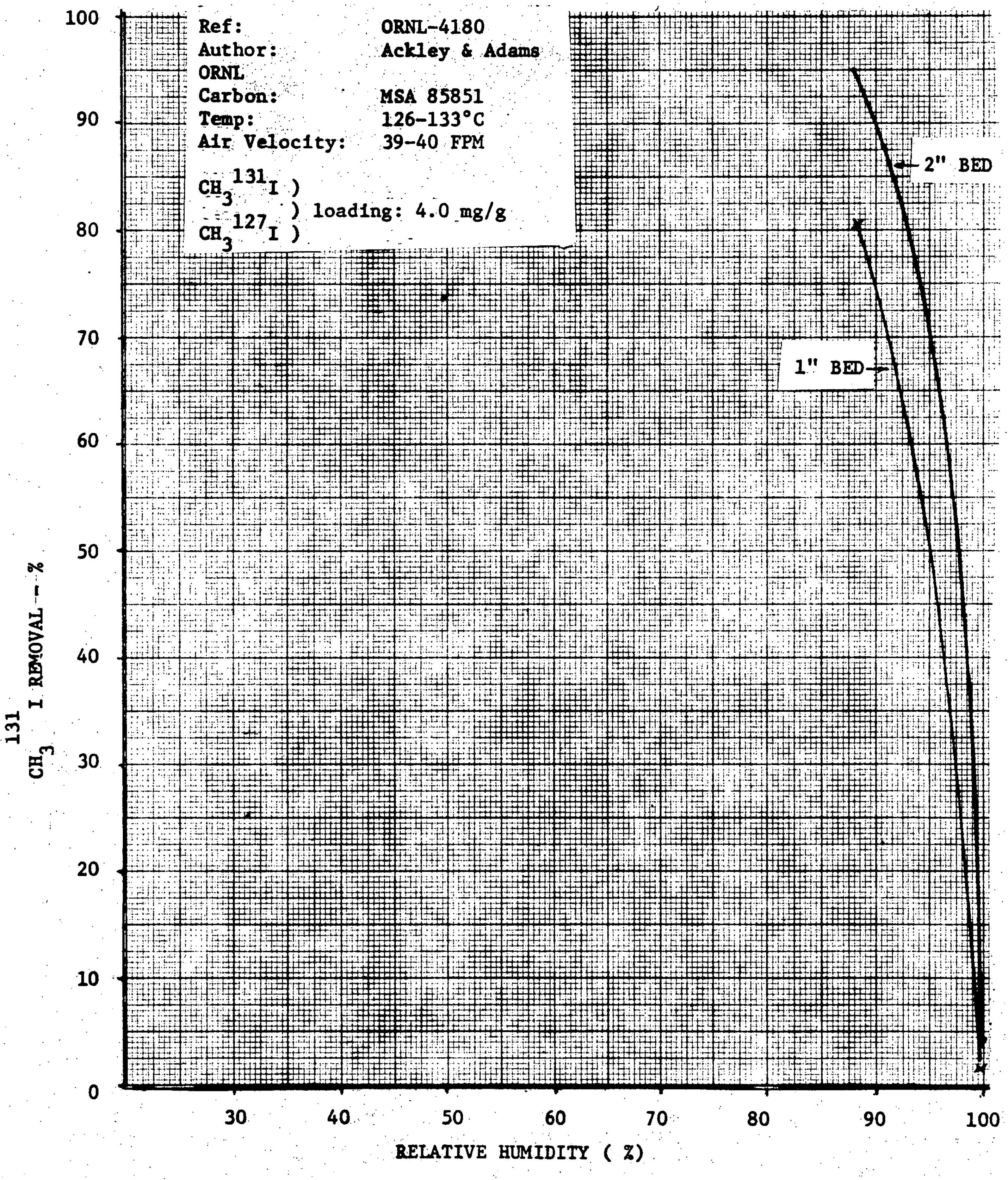
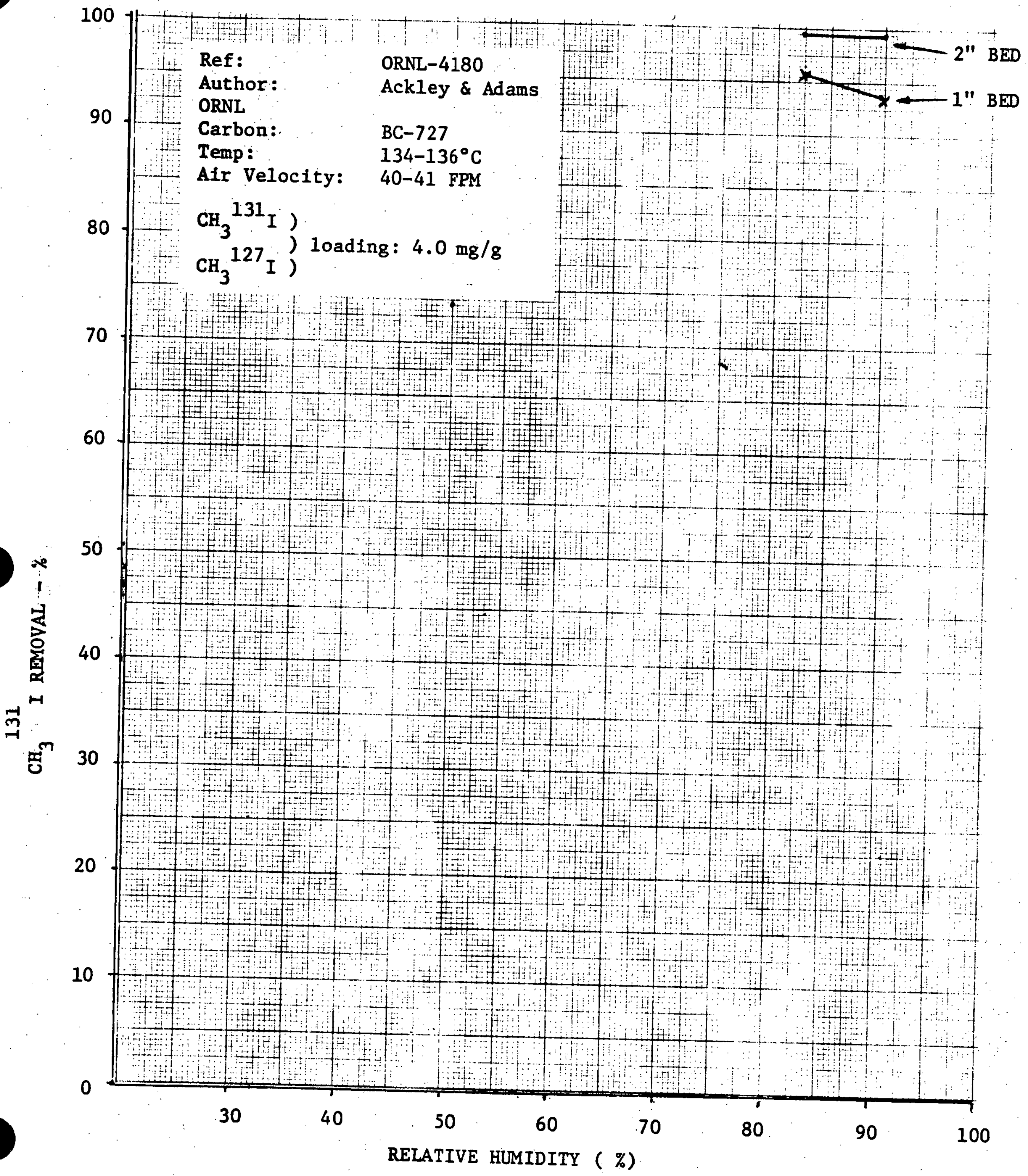
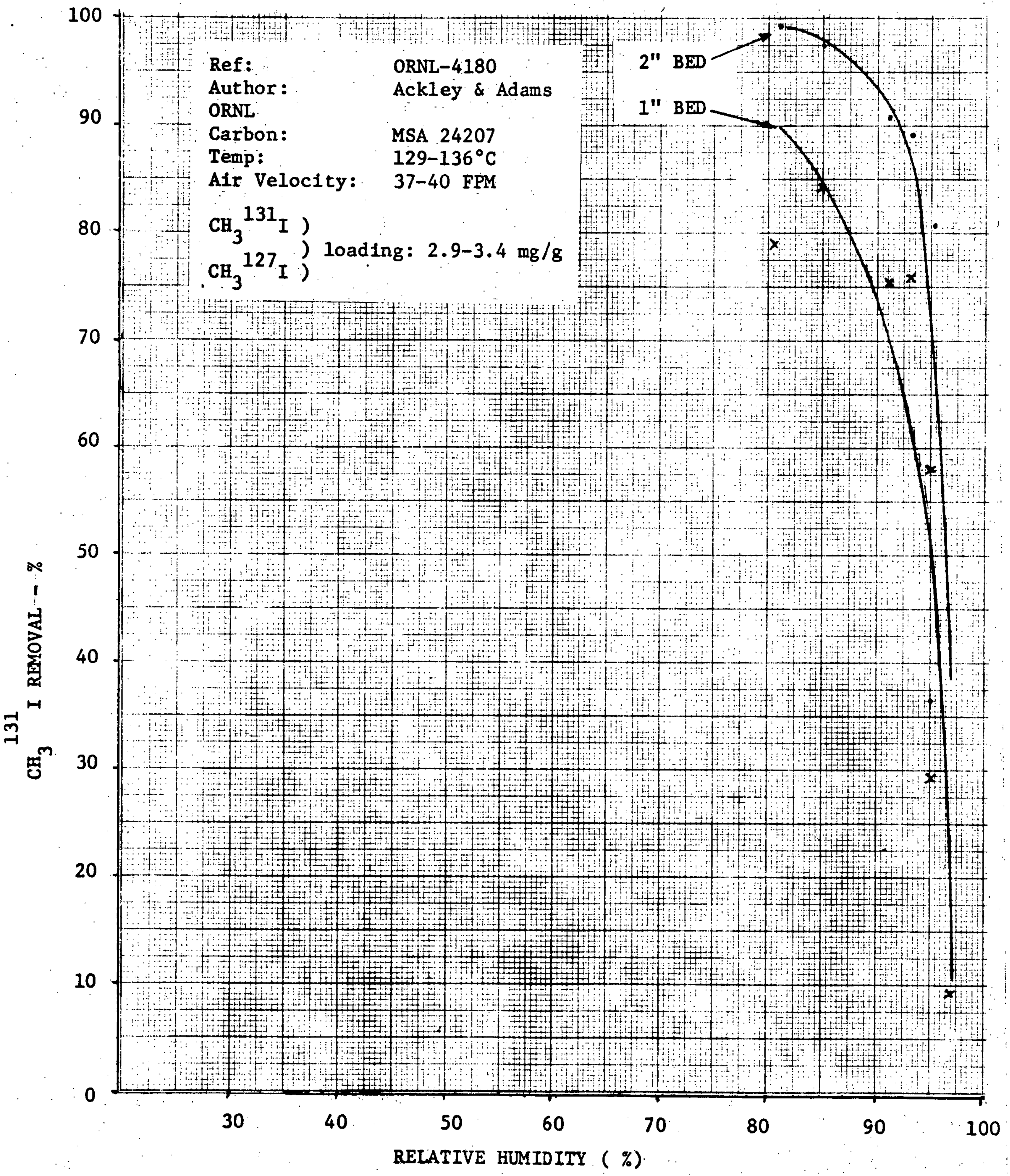

Ref: ORNL-4180
Author: Ackley & Adams
ORNL
Carbon: MSA 85851
Temp: 126-133°C
Air Velocity: 39-40 FPM
$CH_3{}^{131}I$)) loading: 4.0 mg/g $CH_3{}^{127}I$)
2" BED
1" BED
100
90
80
70
60
50
40
30
20
10
0
30
40
50
60
70
80
90
100
RELATIVE HUMIDITY (%)
$CH_3{}^{131}I$ REMOVAL -- %

FIGURE 8



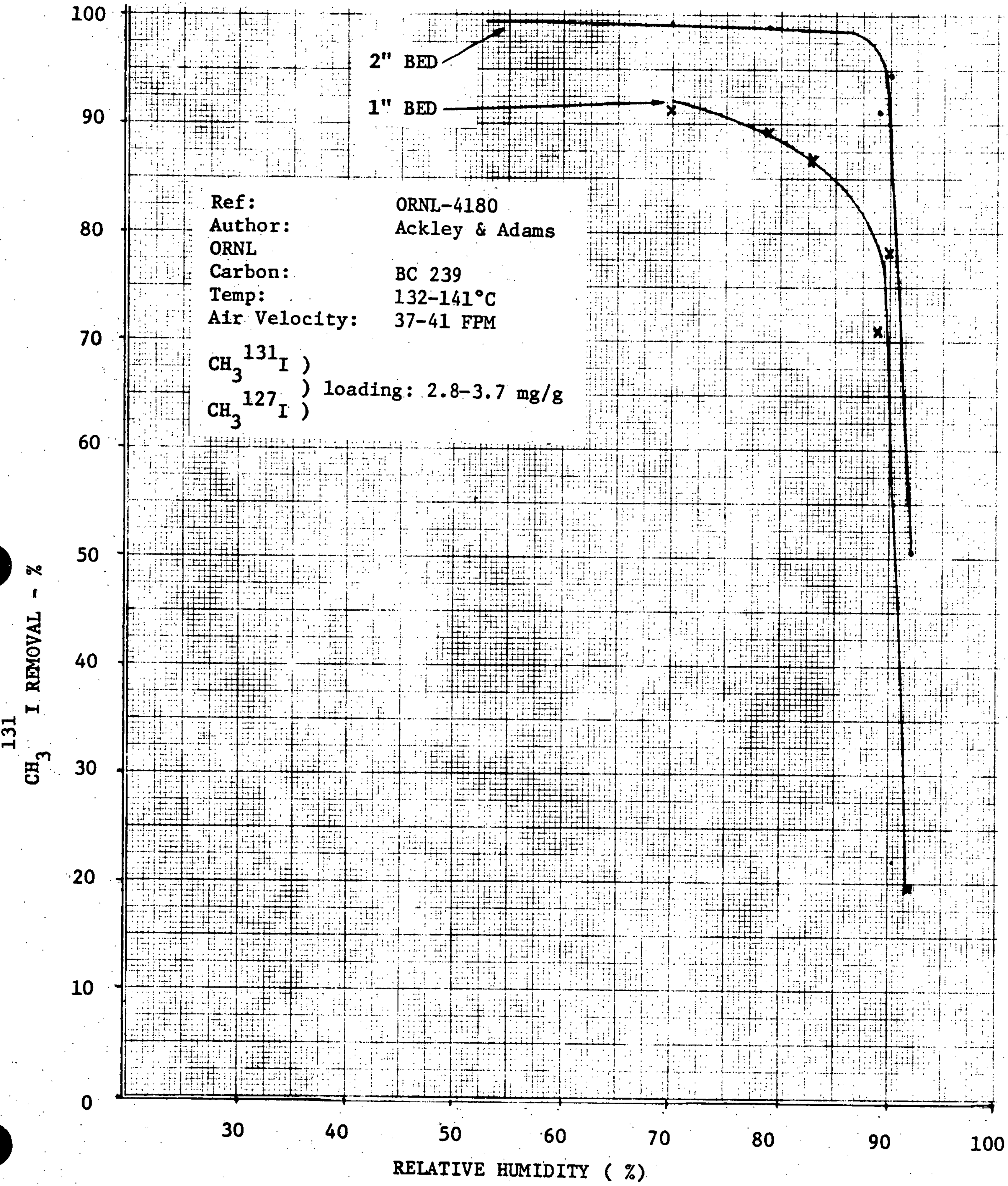
Ref: ORNL-4180
Author: Ackley & Adams
ORNL
Carbon: BC-727
Temp: 134-136°C
Air Velocity: 40-41 FPM
$CH_3{}^{131}I$) loading: 4.0 mg/g
$CH_3{}^{127}I$)
2" BED
1" BED
100
90
80
70
60
50
40
30
20
10
0
30
40
50
60
70
80
90
100
$CH_3{}^{131}I$ REMOVAL - %
RELATIVE HUMIDITY (%)

FIGURE 9



Ref: ORNL-4180
Author: Ackley & Adams
ORNL
Carbon: MSA 24207
Temp: 129-136°C
Air Velocity: 37-40 FPM
$CH_3{}^{131}I$) loading: 2.9-3.4 mg/g
$CH_3{}^{127}I$)
2" BED
1" BED
100
90
80
70
60
50
40
30
20
10
0
30
40
50
60
70
80
90
100
RELATIVE HUMIDITY (%)
$CH_3{}^{131}I$ REMOVAL - %

FIGURE 10



100
90
80
70
60
50
40
30
20
10
0
30
40
50
60
70
80
90
100
2" BED
1" BED
Ref: ORNL-4180
Author: Ackley & Adams
ORNL
Carbon: BC 239
Temp: 132-141°C
Air Velocity: 37-41 FPM
$CH_3{}^{131}I$) loading: 2.8-3.7 mg/g
$CH_3{}^{127}I$)
$CH_3{}^{131}I$ REMOVAL - %
RELATIVE HUMIDITY (%)

FIGURE 11

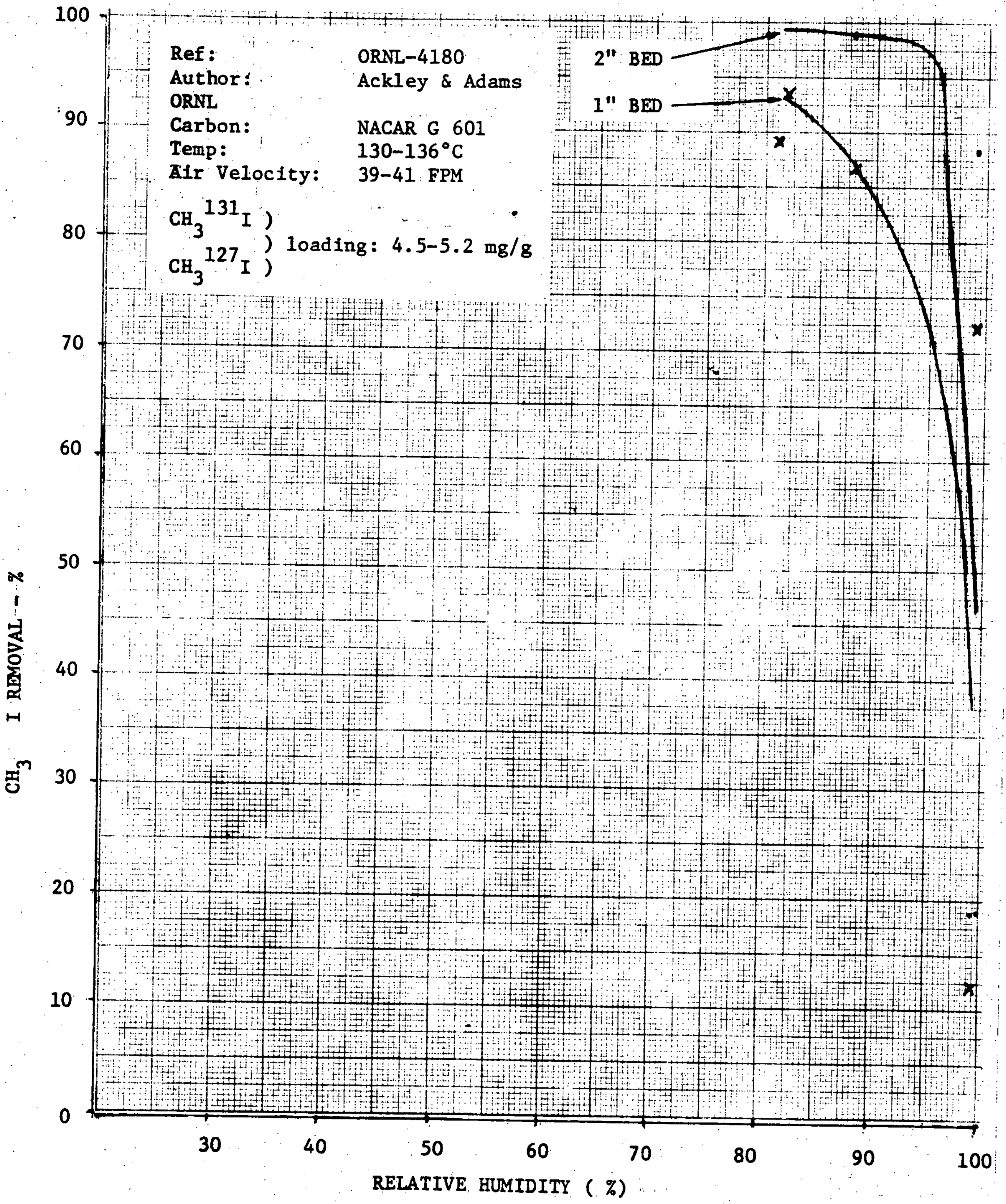

Ref: ORNL-4180
Author: Ackley & Adams
ORNL
Carbon: NACAR G 601
Temp: 130-136°C
Air Velocity: 39-41 FPM
$CH_3{}^{131}I$) loading: 4.5-5.2 mg/g
$CH_3{}^{127}I$)
2" BED
1" BED
100
90
80
70
60
50
40
30
20
10
0
30
40
50
60
70
80
90
100
RELATIVE HUMIDITY (%)
$CH_3{}^{131}I$ REMOVAL - %

FIGURE 12

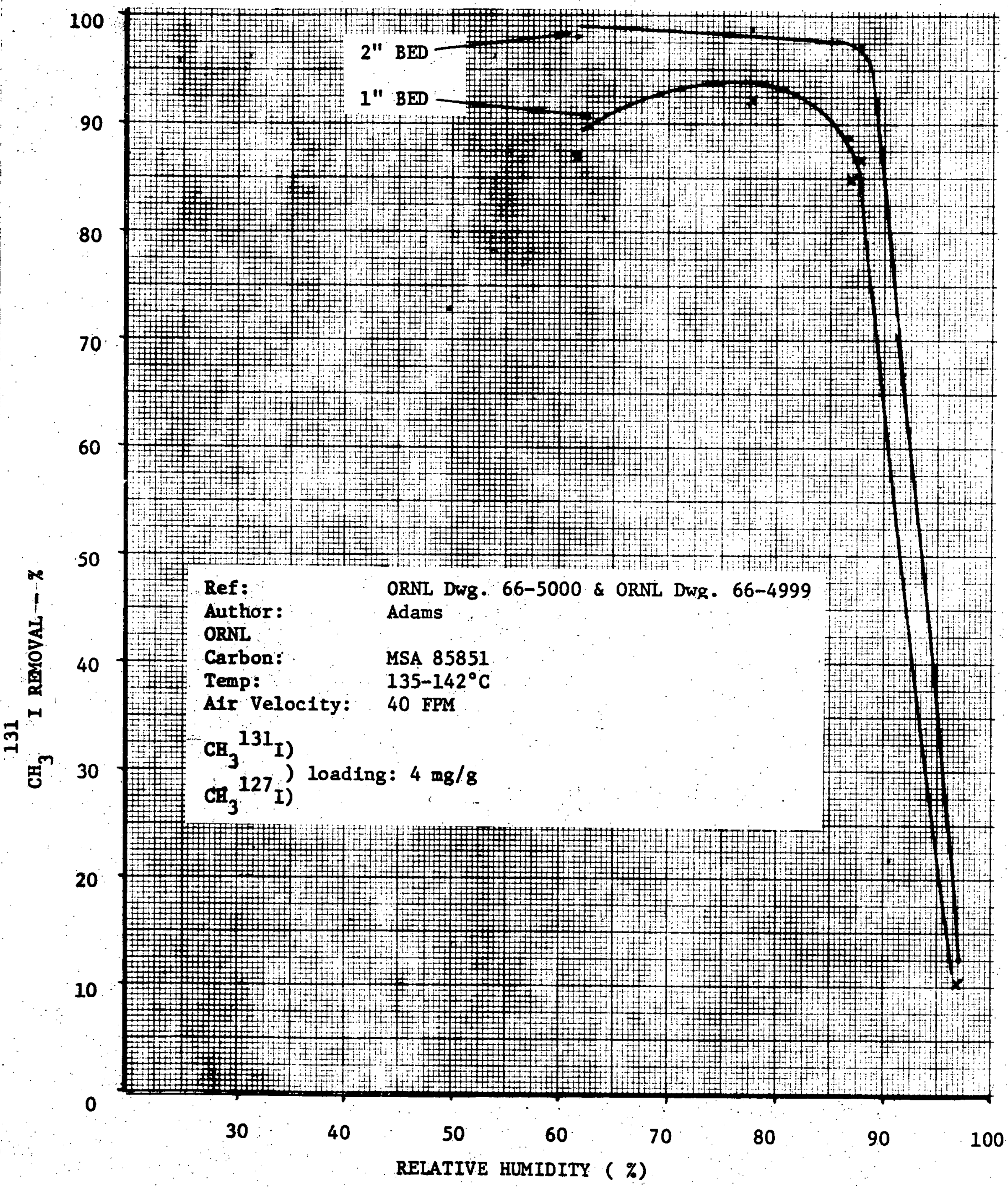

100
90
80
70
60
50
40
30
20
10
0
30
40
50
60
70
80
90
100
$CH_3^{131}I$ REMOVAL — %
RELATIVE HUMIDITY (%)
2" BED
1" BED
Ref: ORNL Dwg. 66-5000 & ORNL Dwg. 66-4999
Author: Adams
ORNL
Carbon: MSA 85851
Temp: 135-142°C
Air Velocity: 40 FPM
$CH_3{}^{131}I$)) loading: 4 mg/g $CH_3{}^{127}I$)

FIGURE 13

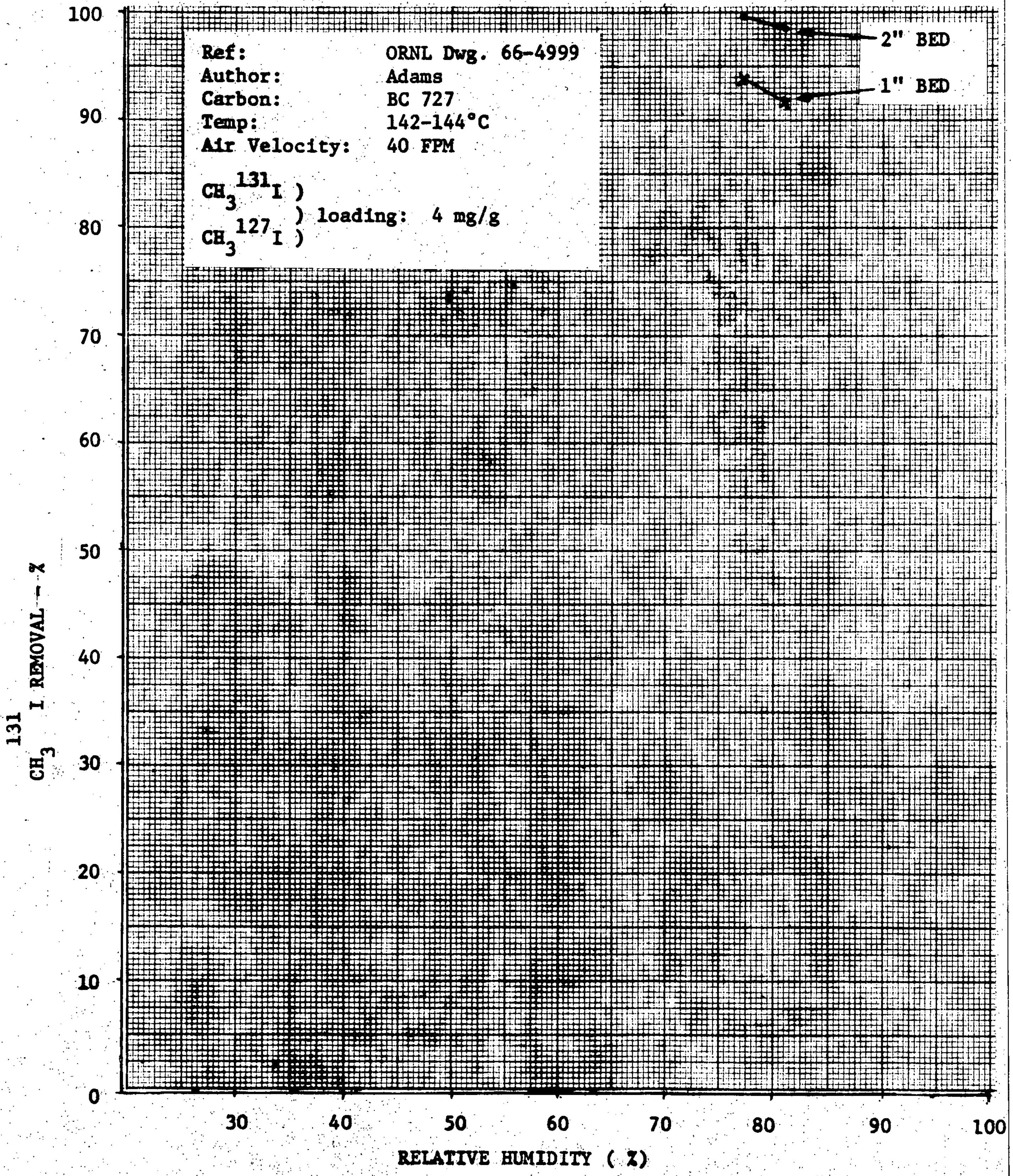

Ref: ORNL Dwg. 66-4999
Author: Adams
Carbon: BC 727
Temp: 142-144°C
Air Velocity: 40 FPM
$CH_3{}^{131}I$) loading: 4 mg/g
$CH_3{}^{127}I$)
2" BED
1" BED
$CH_3{}^{131}I$ REMOVAL — %
0
10
20
30
40
50
60
70
80
90
100
30
40
50
60
70
80
90
100
RELATIVE HUMIDITY (%)

FIGURE 14

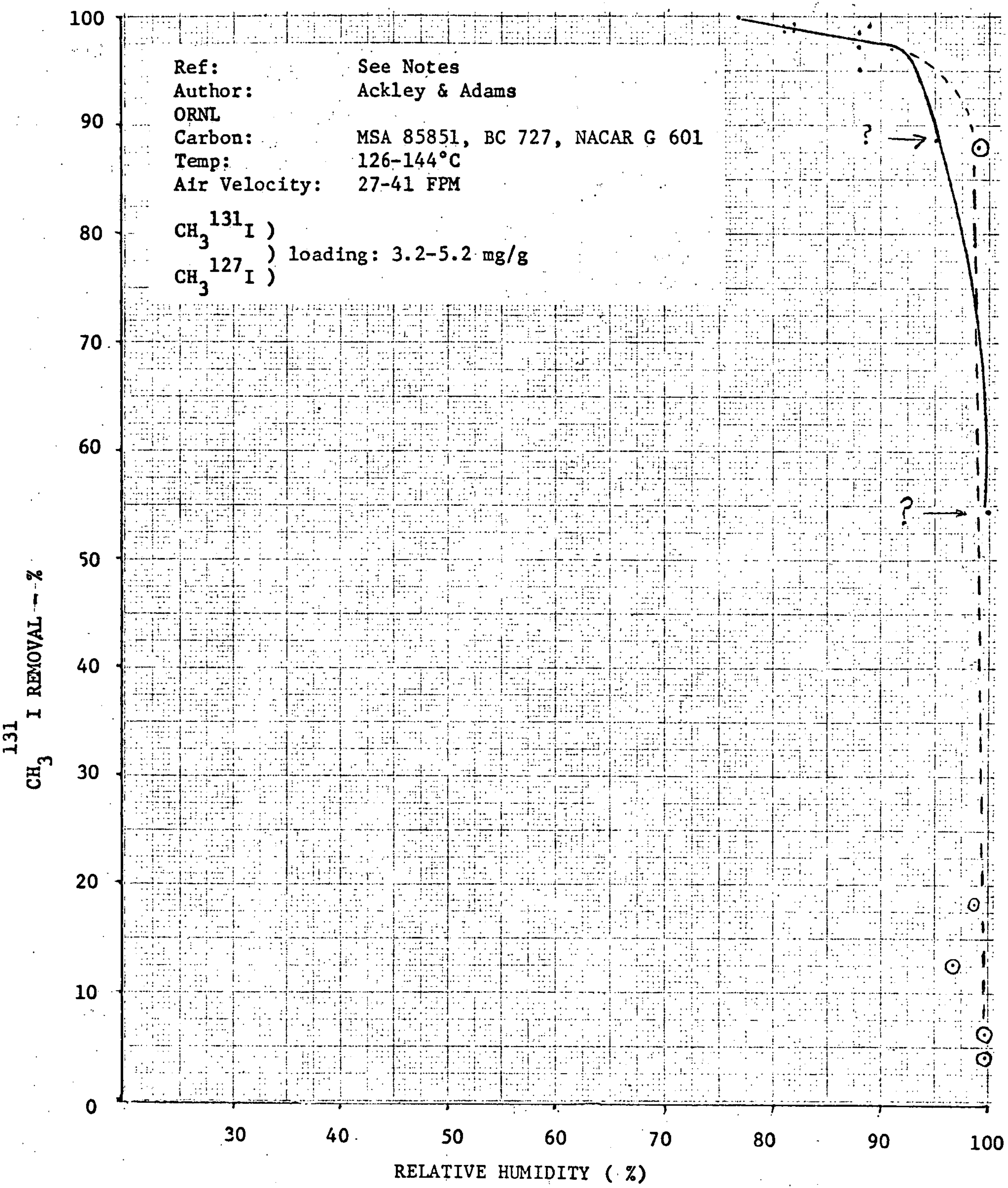
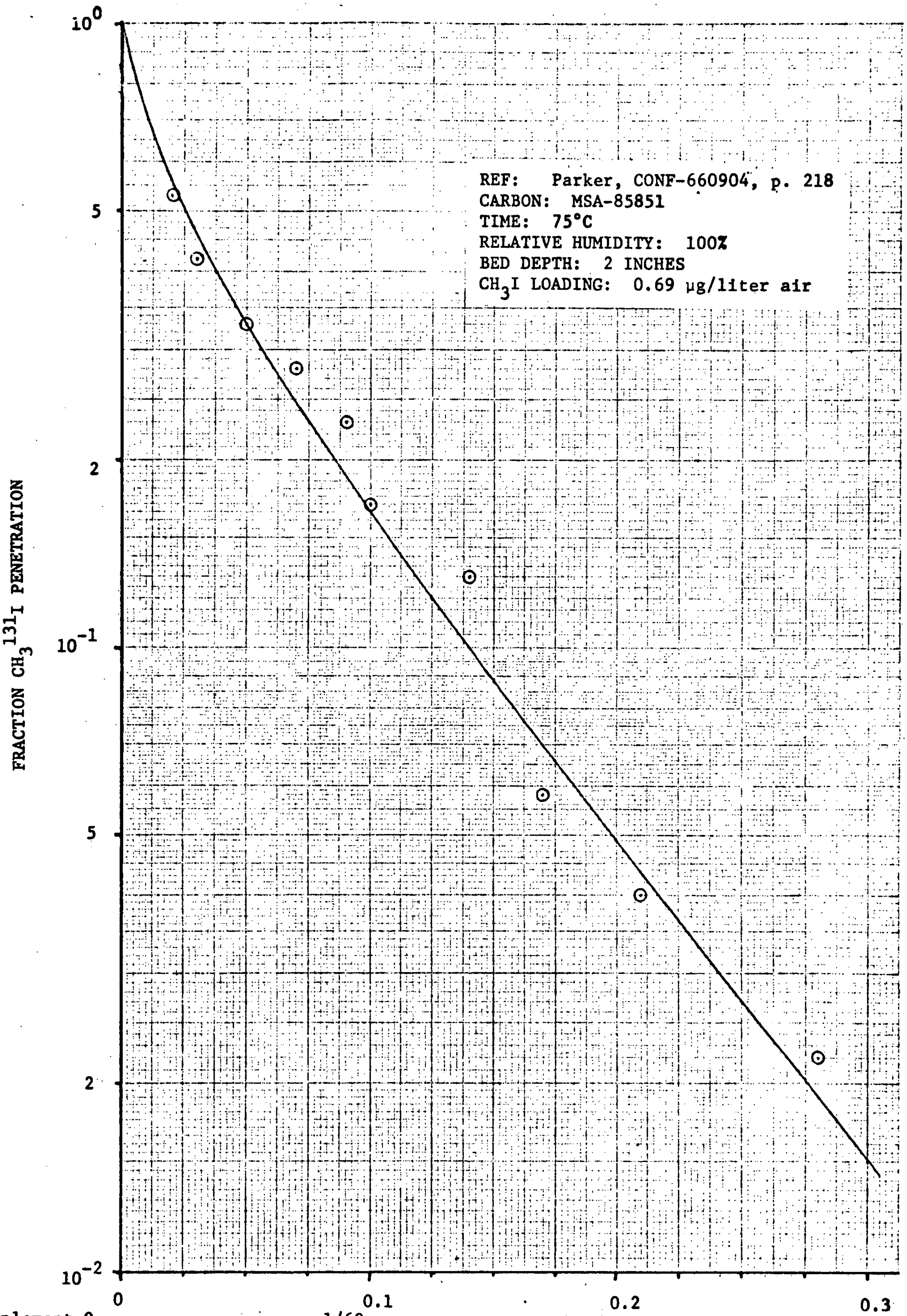

Ref: See Notes
Author: Ackley & Adams
ORNL
Carbon: MSA 85851, BC 727, NACAR G 601
Temp: 126-144°C
Air Velocity: 27-41 FPM
$CH_3{}^{131}I$) loading: 3.2-5.2 mg/g
$CH_3{}^{127}I$)
?
?
100
90
80
70
60
50
40
30
20
10
0
30
40
50
60
70
80
90
100
$CH_3{}^{131}I$ REMOVAL -- %
RELATIVE HUMIDITY (%)

FIGURE 15



REF: Parker, CONF-660904, p. 218
CARBON: MSA-85851
TIME: 75°C
RELATIVE HUMIDITY: 100%
BED DEPTH: 2 INCHES
CH$_3$I LOADING: 0.69 μg/liter air

FIGURE 16

Ref: Letter D. A. Collins TRG(W)/DAC/LAJ - 6347
UKAEA
Carbon: BC. 727
Temp: 20°C
Air Velocity: 50 FPM for 2" bed
CH_3I loading: 100 μg/g
Residence Time: 0.2 sec

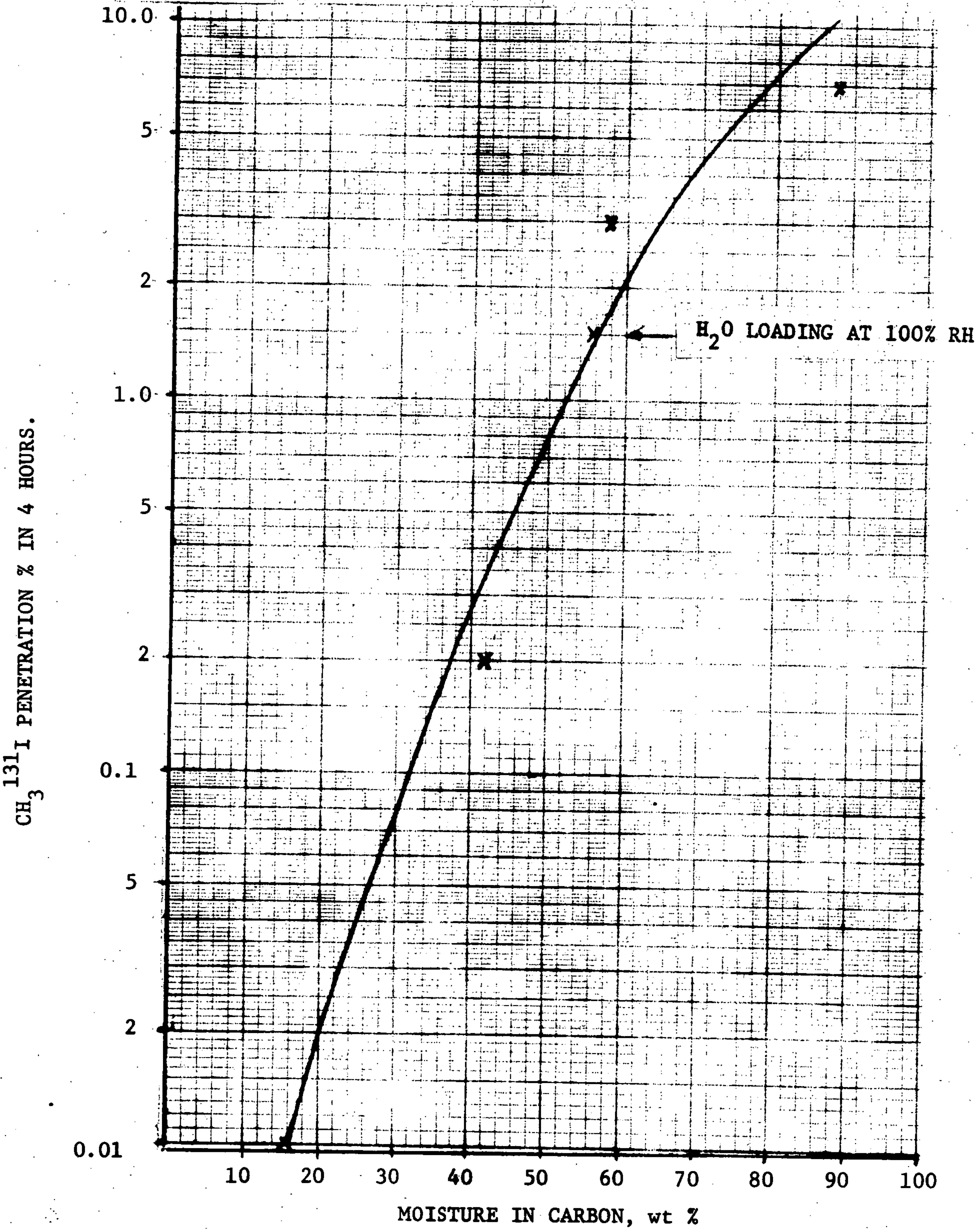


FIGURE 17

Ref: TRG 1300 W
Author: Collins et al.
UKAEA
Carbon: 207B 0.5% KI
Temp: 25°C

$CH_3{}^{131}I$)
$CH_3{}^{127}I$) loading: 100 μg/g

RH: 98-100%

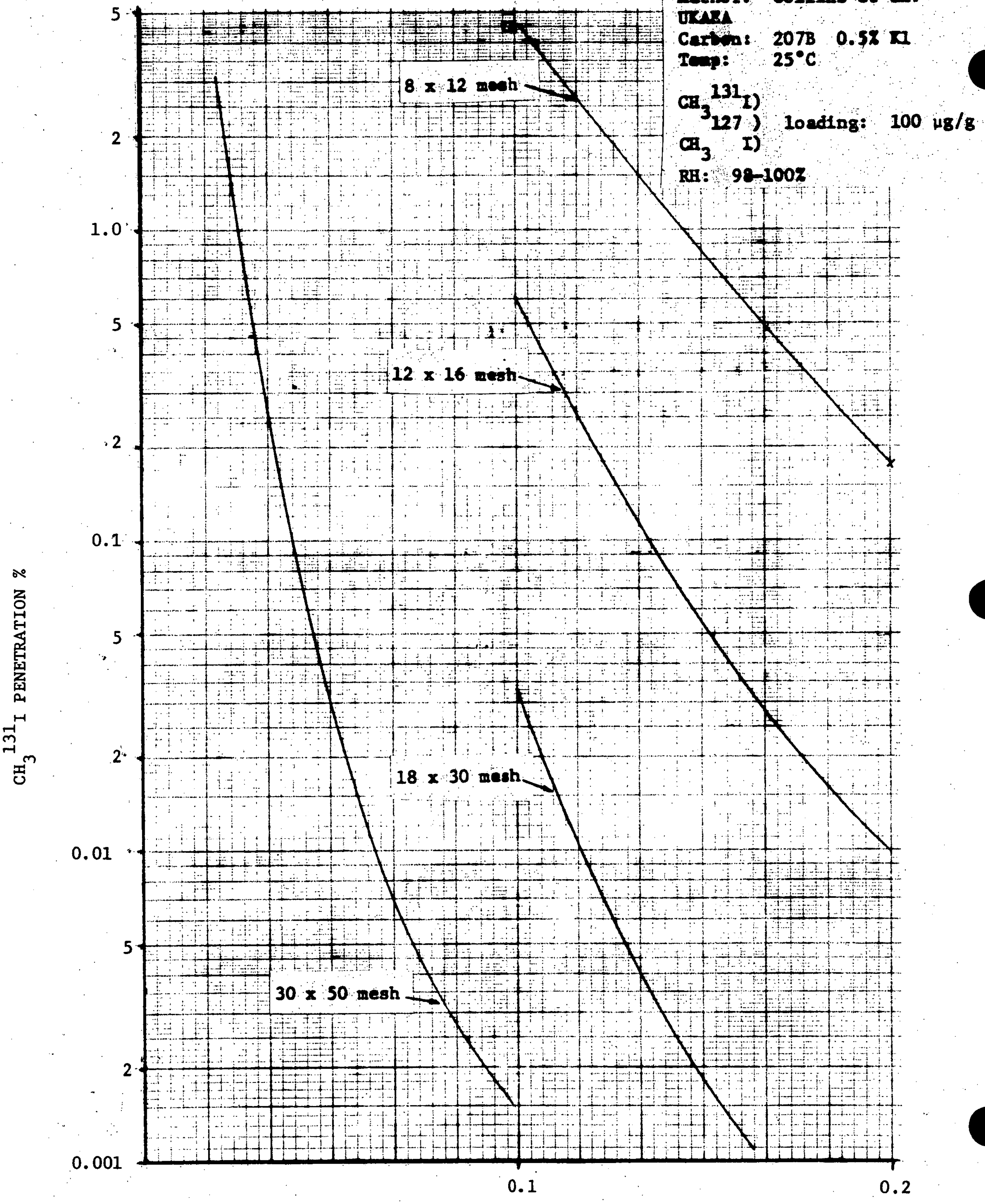
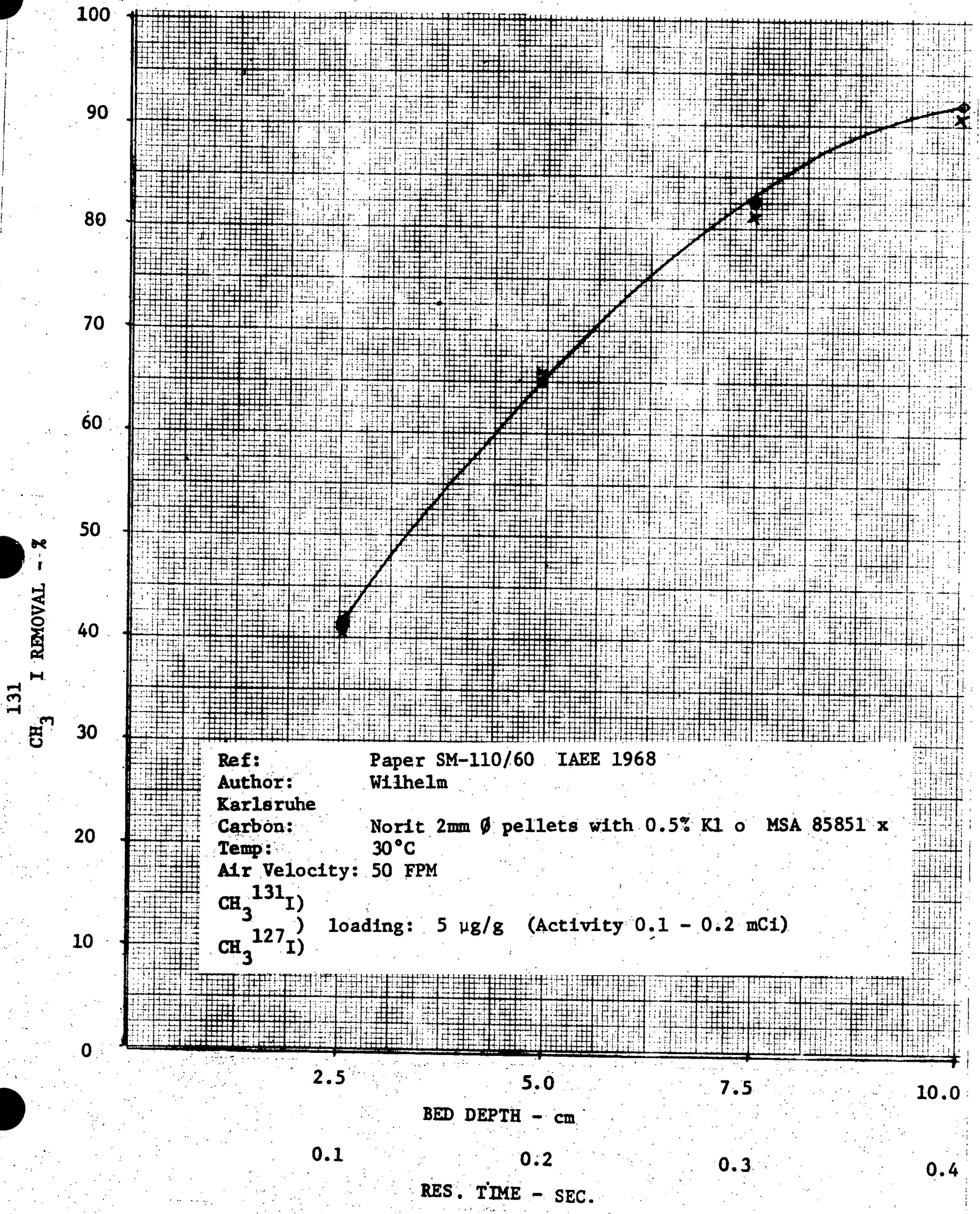
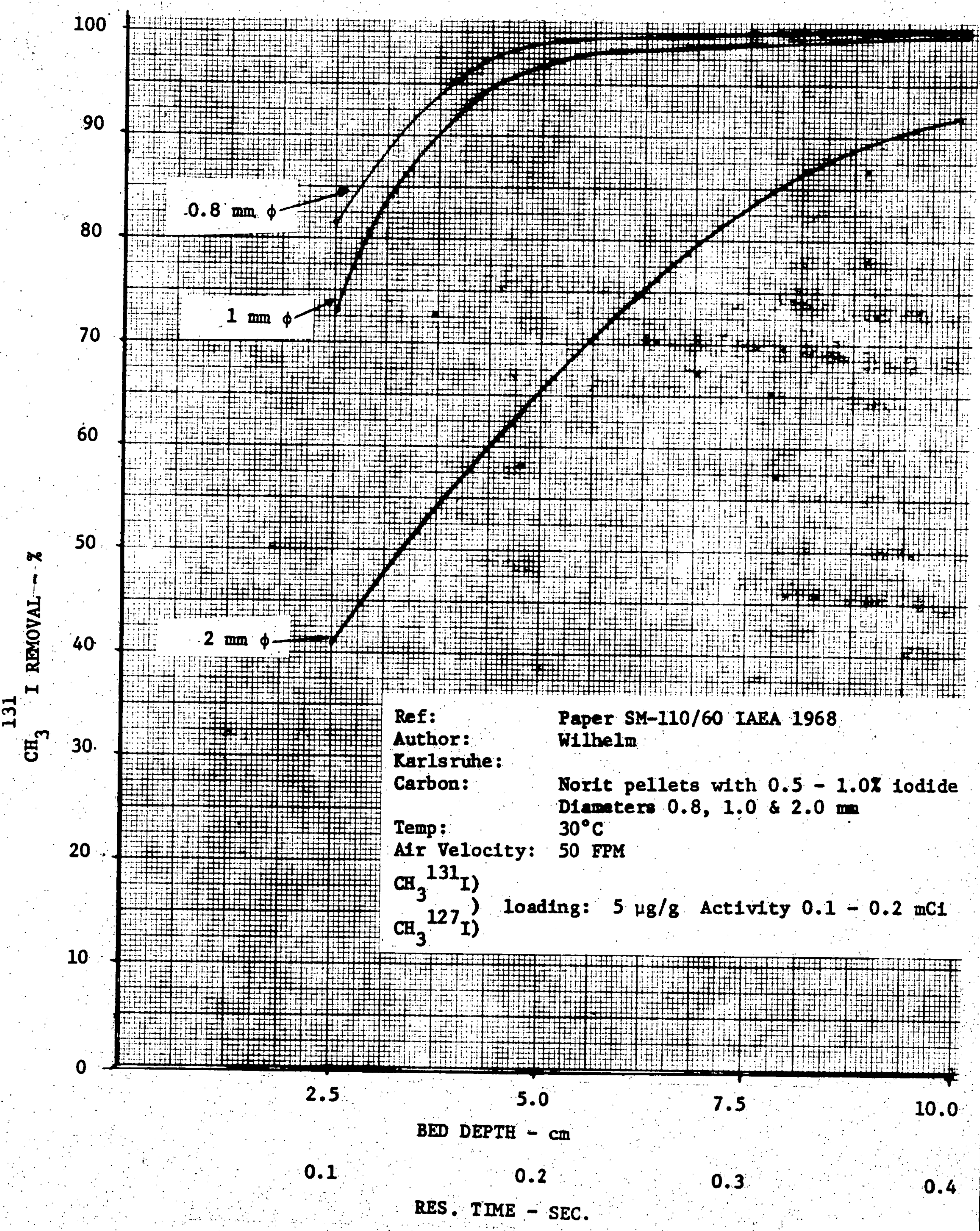


FIGURE 18



Ref: Paper SM-110/60 IAEE 1968
Author: Wilhelm
Karlsruhe
Carbon: Norit 2mm Ø pellets with 0.5% Kl o MSA 85851 x
Temp: 30°C
Air Velocity: 50 FPM
$CH_3{}^{131}I$)
) loading: 5 μg/g (Activity 0.1 - 0.2 mCi)
$CH_3{}^{127}I$)

FIGURE 19



Ref: Paper SM-110/60 IAEA 1968
Author: Wilhelm
Karlsruhe:
Carbon: Norit pellets with 0.5 - 1.0% iodide
Diameters 0.8, 1.0 & 2.0 mm
Temp: 30°C
Air Velocity: 50 FPM
$CH_3{}^{131}I$) $CH_3{}^{127}I$) loading: 5 μg/g Activity 0.1 - 0.2 mCi

FIGURE 20

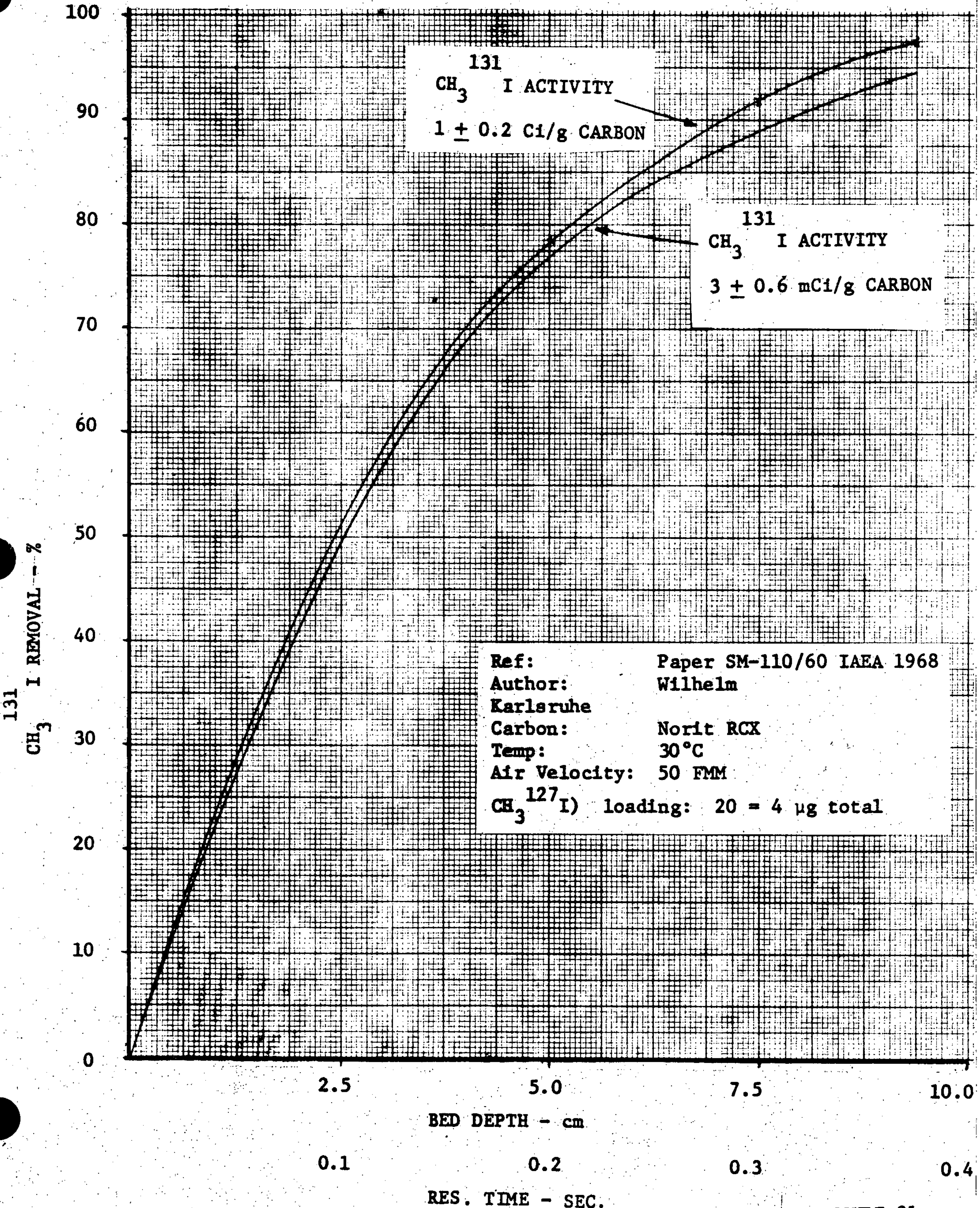
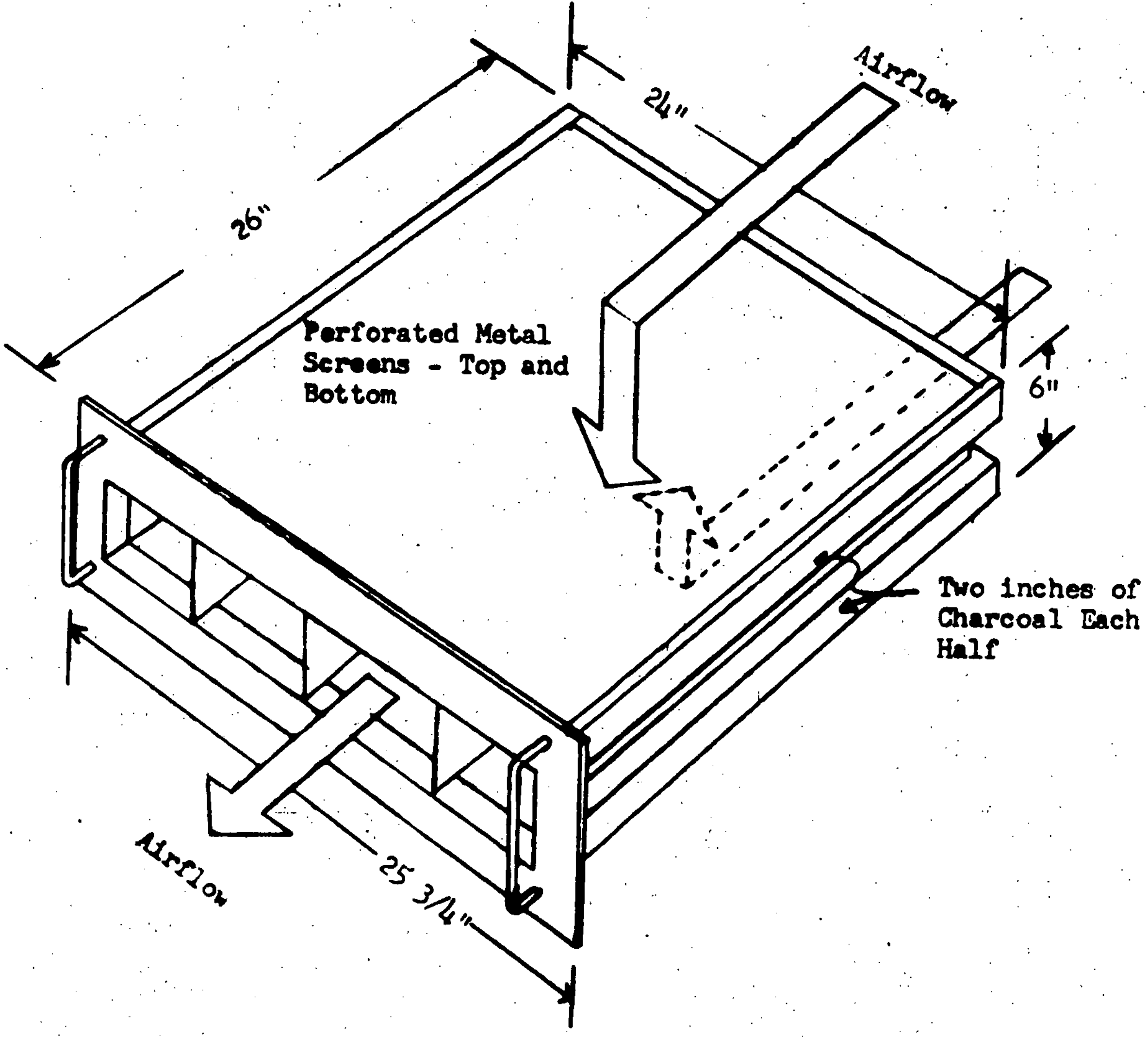

$CH_3{}^{131}I$ ACTIVITY
1 ± 0.2 Ci/g CARBON
$CH_3{}^{131}I$ ACTIVITY
3 ± 0.6 mCi/g CARBON
Ref: Paper SM-110/60 IAEA 1968
Author: Wilhelm
Karlsruhe
Carbon: Norit RCX
Temp: 30°C
Air Velocity: 50 FMM
$CH_3{}^{127}I$) loading: 20 = 4 μg total
$CH_3{}^{131}I$ REMOVAL - %
100
90
80
70
60
50
40
30
20
10
0
2.5
5.0
7.5
10.0
BED DEPTH - cm
0.1
0.2
0.3
0.4
RES. TIME - SEC.

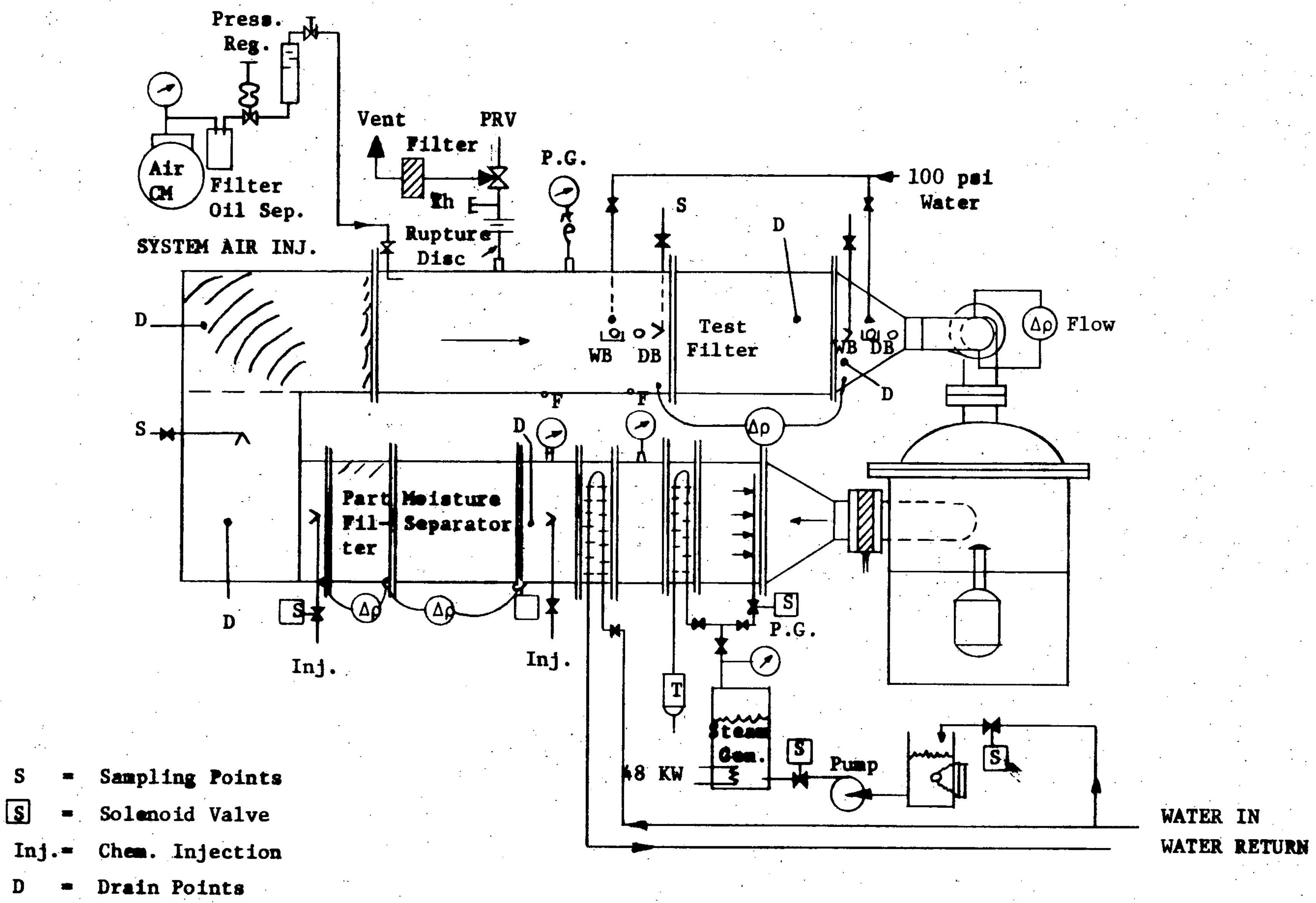
FIGURE 21



SKETCH OF TYPICAL CONNECTICUT YANKEE CHARCOAL FILTER

FIGURE 22

FIGURE 23



PLANT VIEW OF FILTER TEST LOOP

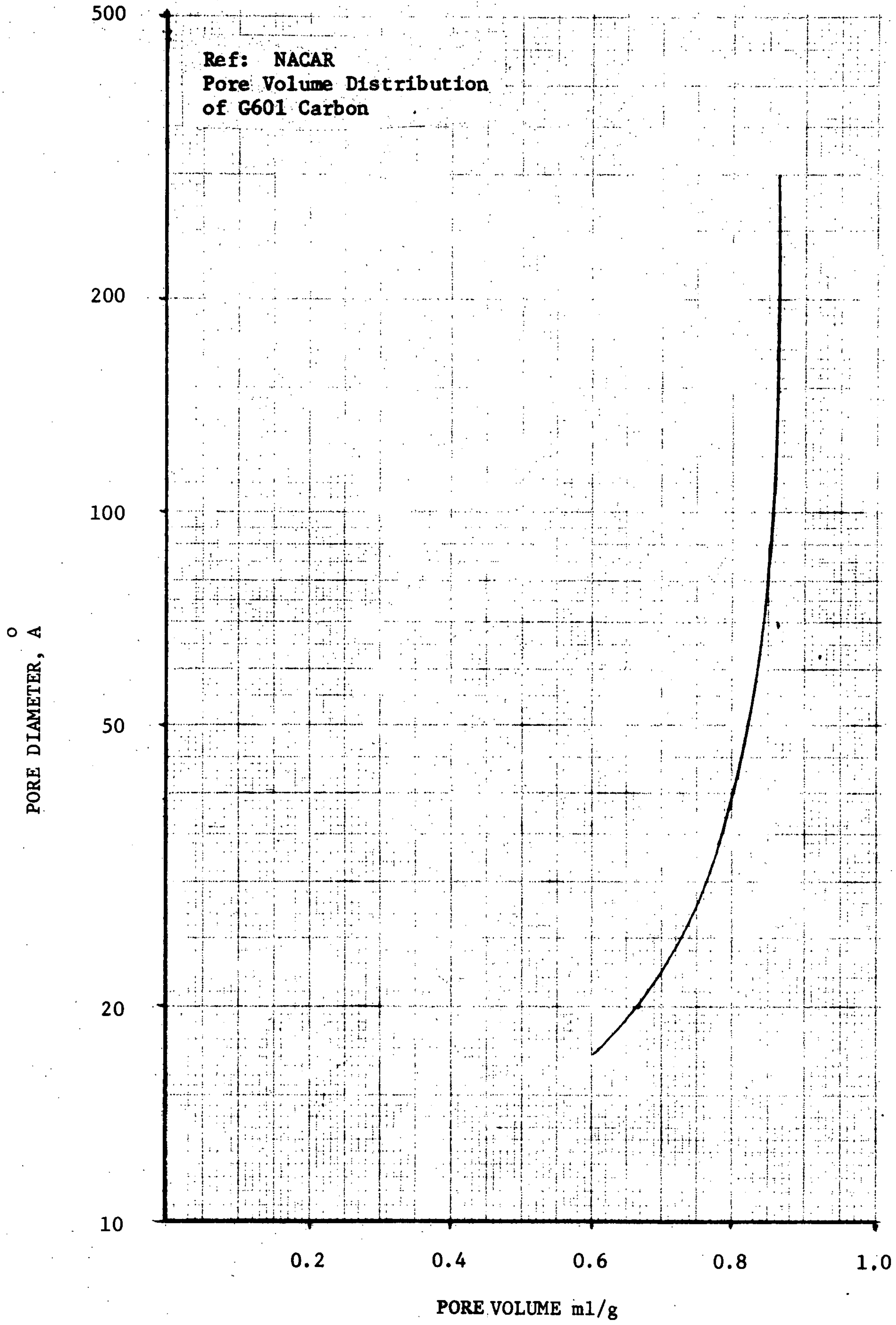
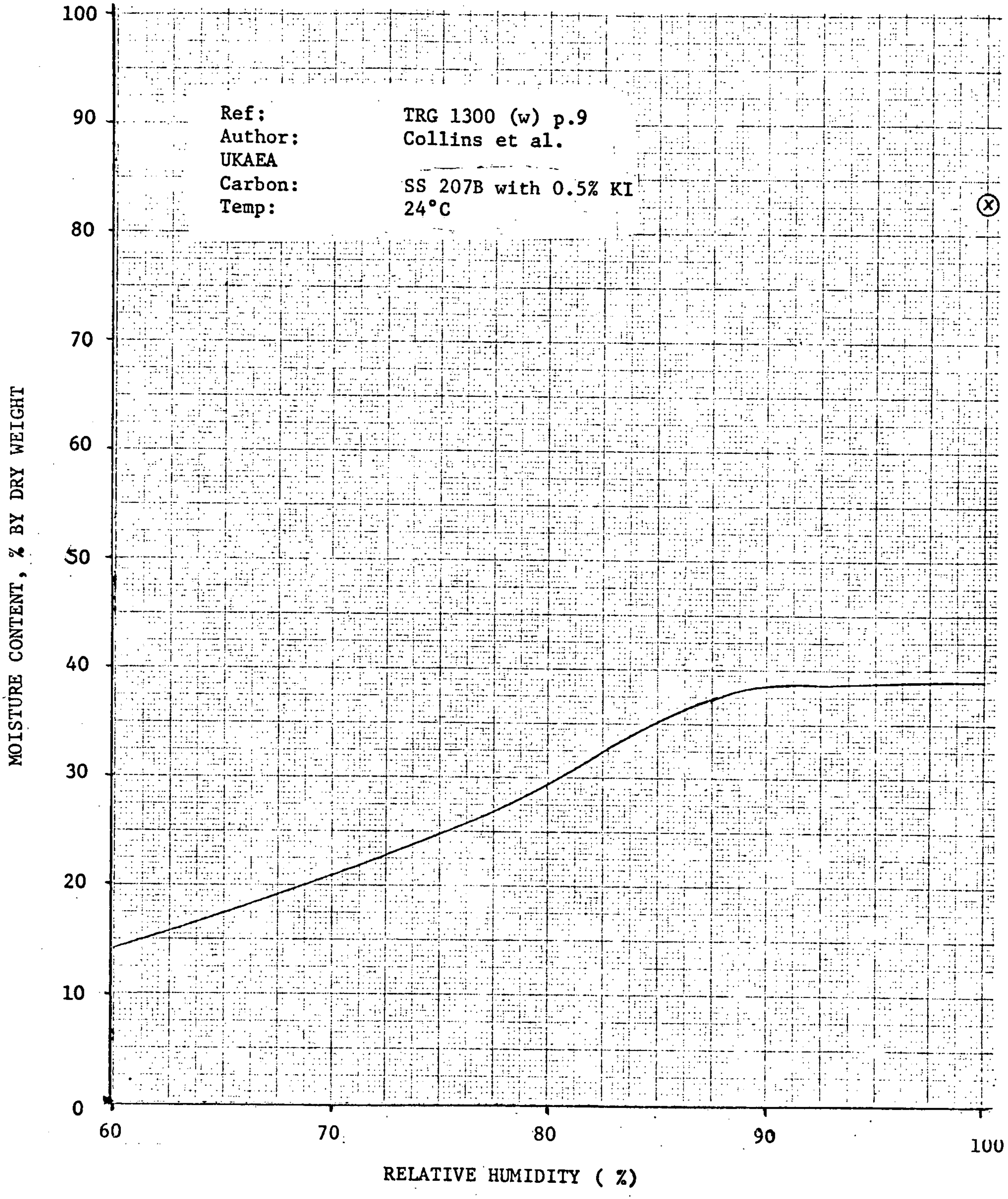

Ref: NACAR
Pore Volume Distribution
of G601 Carbon
500
200
100
50
20
10
PORE DIAMETER, Å
0.2
0.4
0.6
0.8
1.0
PORE VOLUME ml/g

FIGURE 25

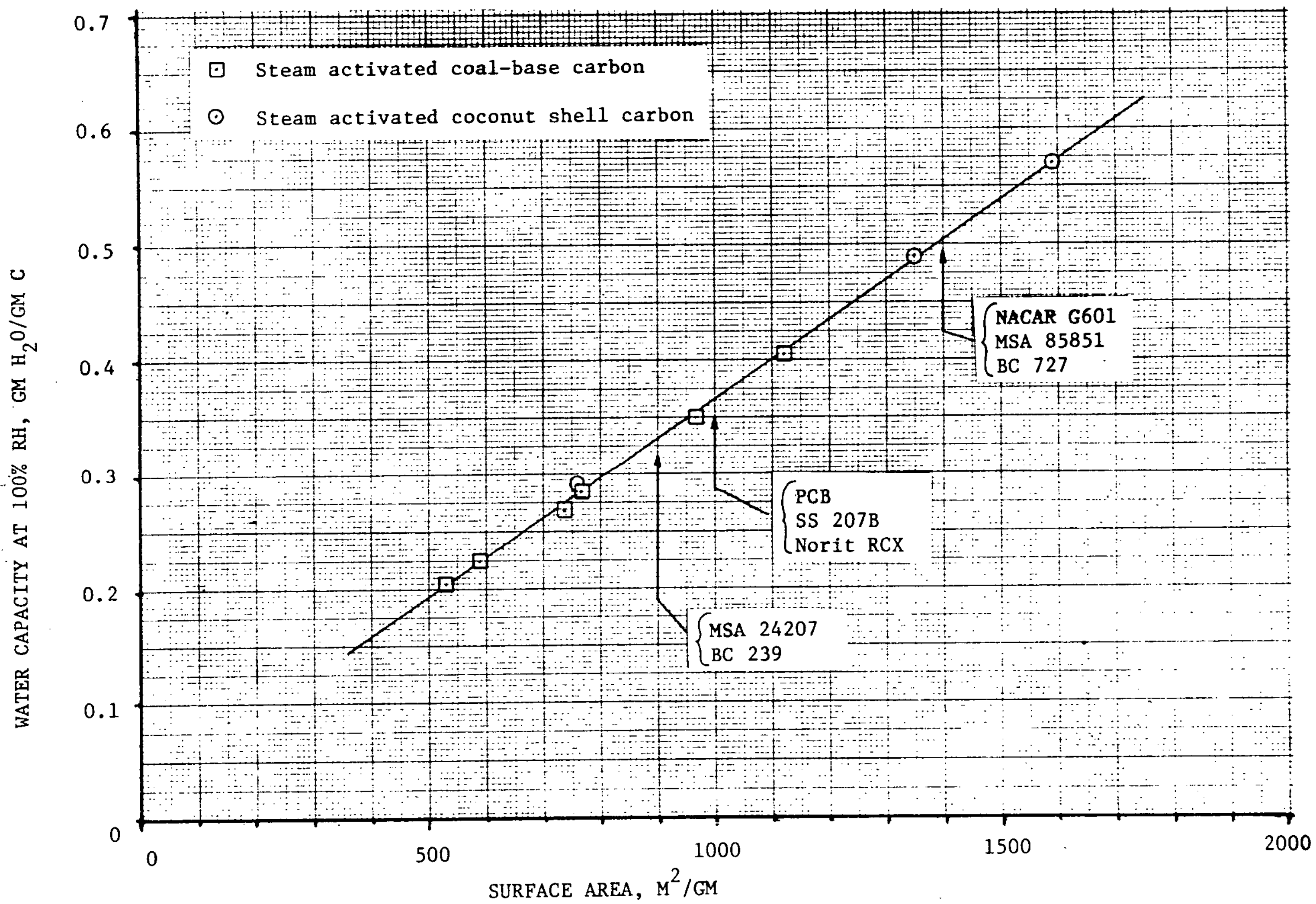


Ref: TRG 1300 (w) p.9
Author: Collins et al.
UKAEA
Carbon: SS 207B with 0.5% KI
Temp: 24°C
100
90
80
70
60
50
40
30
20
10
0
60
70
80
90
100
MOISTURE CONTENT, % BY DRY WEIGHT
RELATIVE HUMIDITY (%)

FIGURE 27

FIGURE 28

MAXIMUM WATER ADSORPTION CAPACITY OF CARBONS 100% RH 100°C



Ref: Paper SM-110/60 IAEA 1968
Author: Wilhelm
Karlsruhc
Carbon: Norit 0.5% KI 2mm ϕ
Temp: 31.2°C
RH: 100%

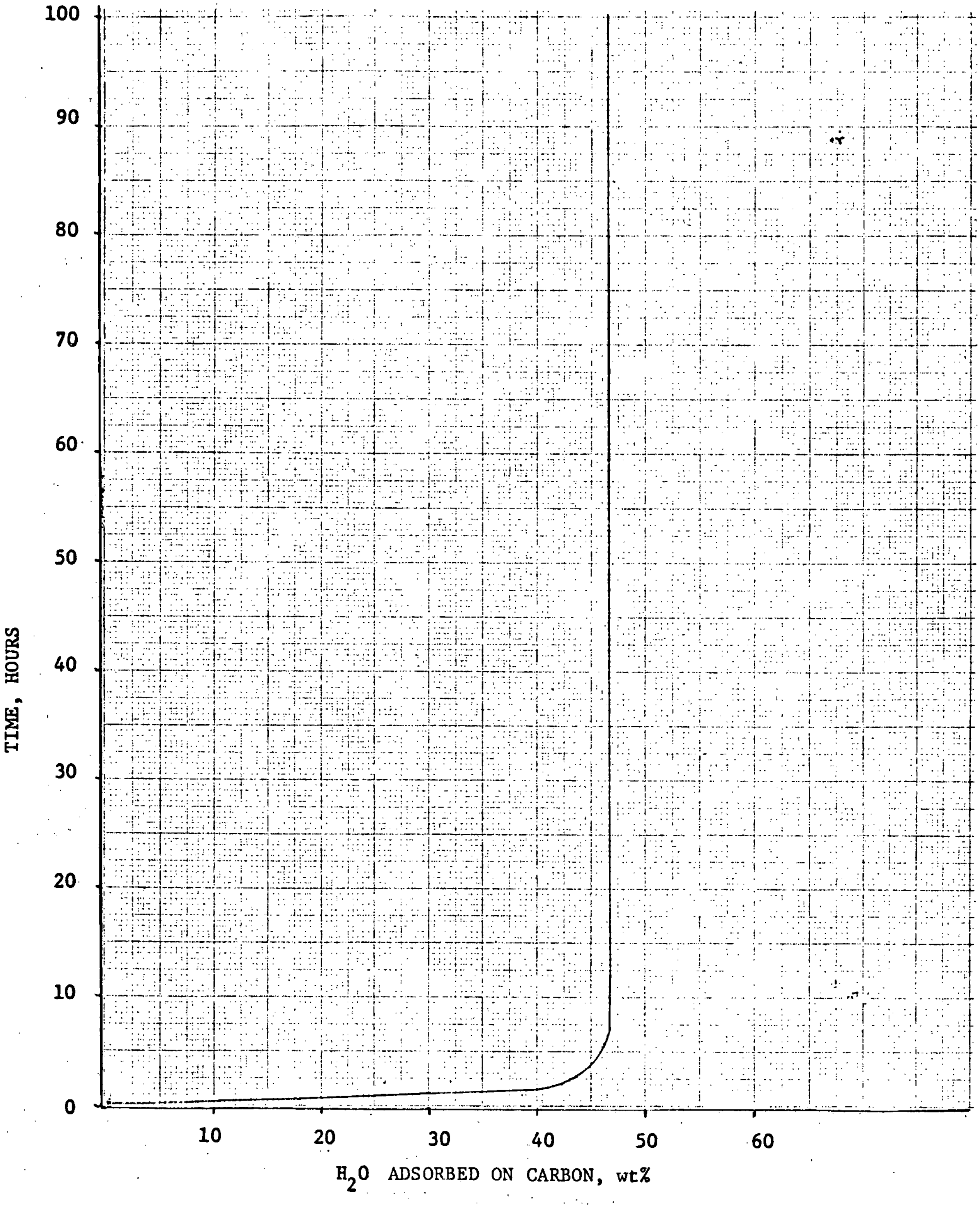
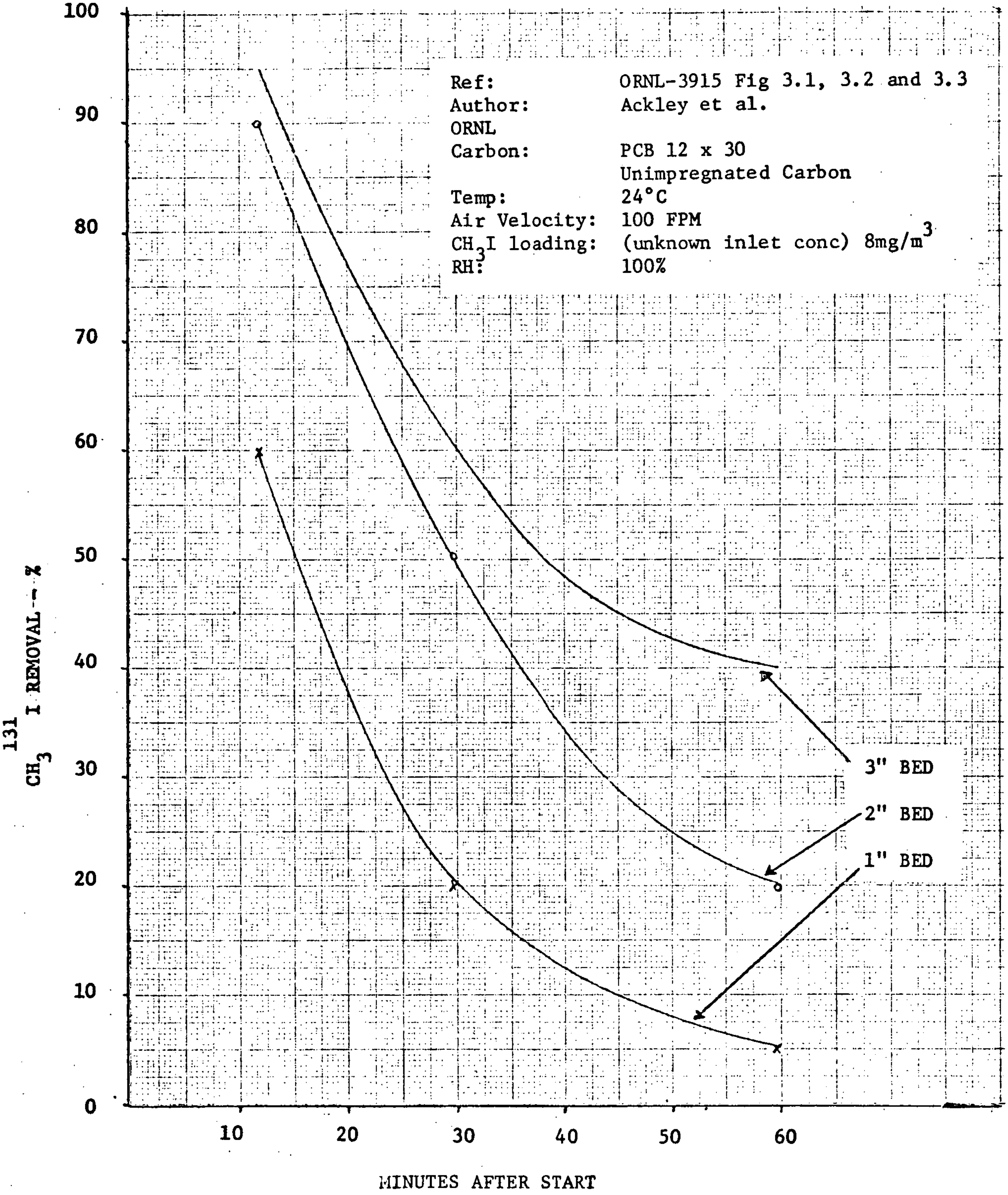
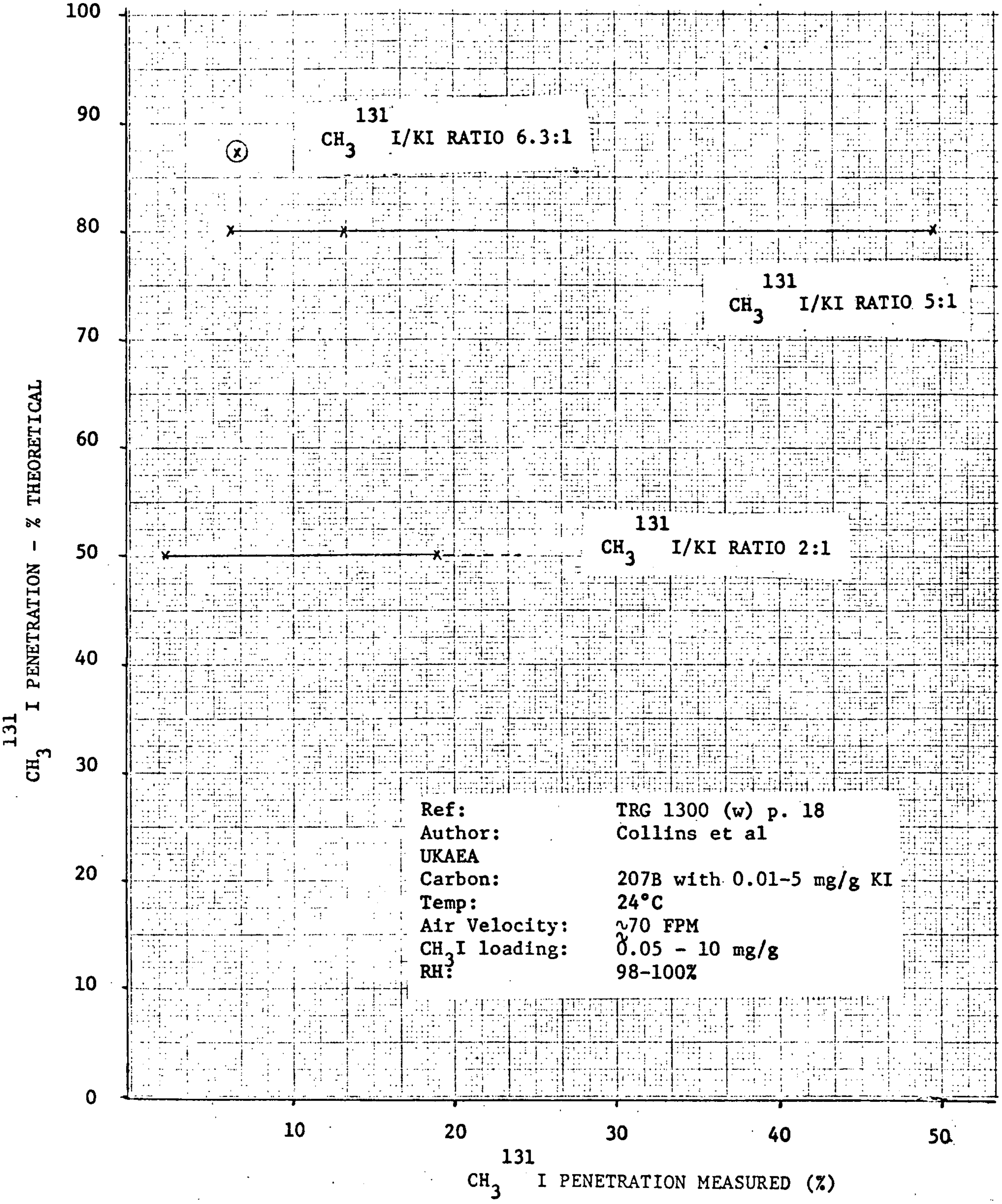


FIGURE 29



Ref: ORNL-3915 Fig 3.1, 3.2 and 3.3
Author: Ackley et al.
ORNL
Carbon: PCB 12 x 30
Unimpregnated Carbon
Temp: 24°C
Air Velocity: 100 FPM
CH_3I loading: (unknown inlet conc) 8mg/m^3
RH: 100%

FIGURE 30



Ref: TRG 1300 (w) p. 18
Author: Collins et al
UKAEA
Carbon: 207B with 0.01-5 mg/g KI
Temp: 24°C
Air Velocity: ~70 FPM
CH_3I loading: ~0.05 - 10 mg/g
RH: 98-100%

FIGURE 31

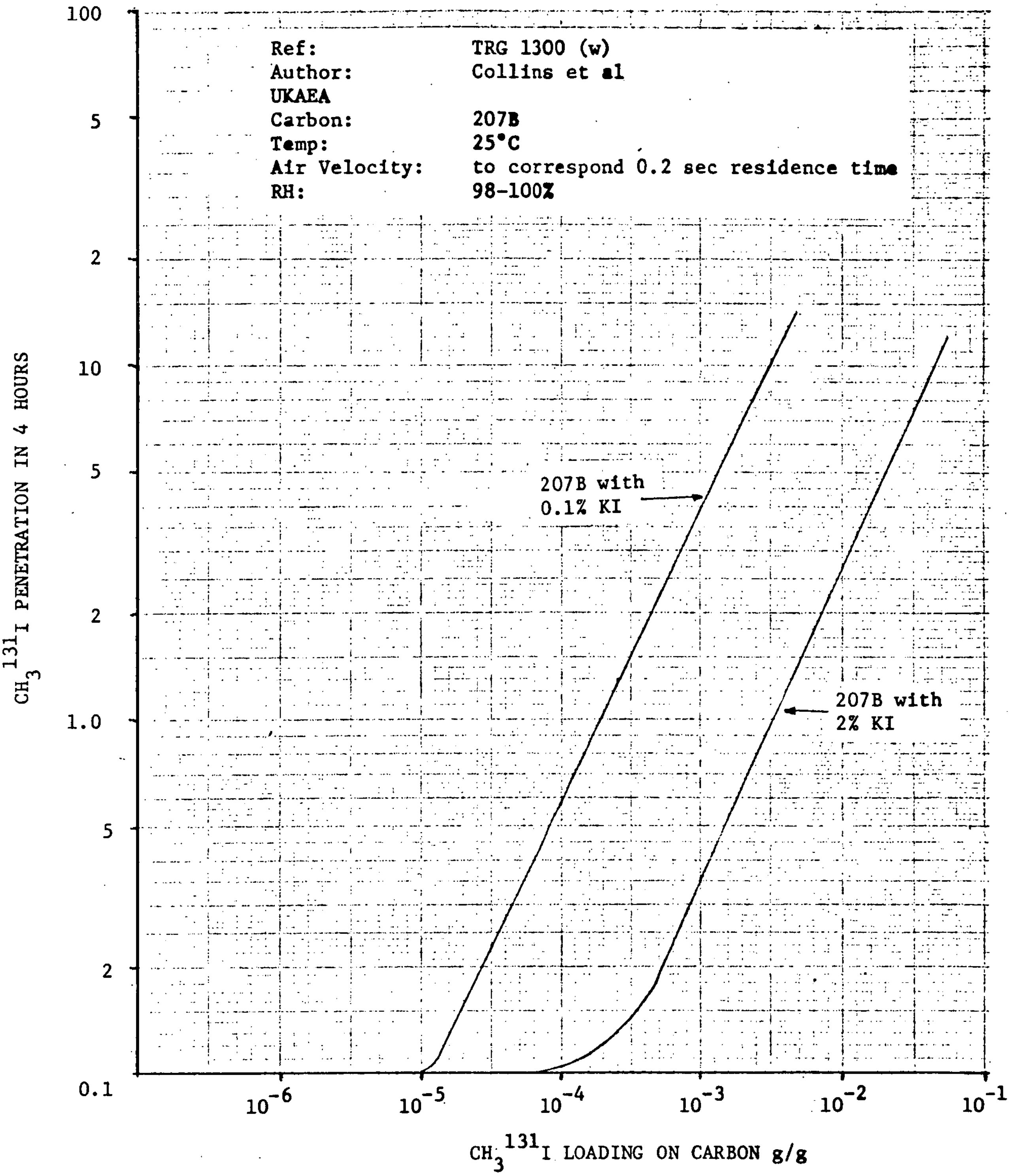

Ref: TRG 1300 (w)
Author: Collins et al
UKAEA
Carbon: 207B
Temp: 25°C
Air Velocity: to correspond 0.2 sec residence time
RH: 98-100%
100
5
2
10
5
2
1.0
5
2
0.1
$CH_3{}^{131}I$ PENETRATION IN 4 HOURS
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
$CH_3{}^{131}I$ LOADING ON CARBON g/g
207B with 0.1% KI
207B with 2% KI

FIGURE 32

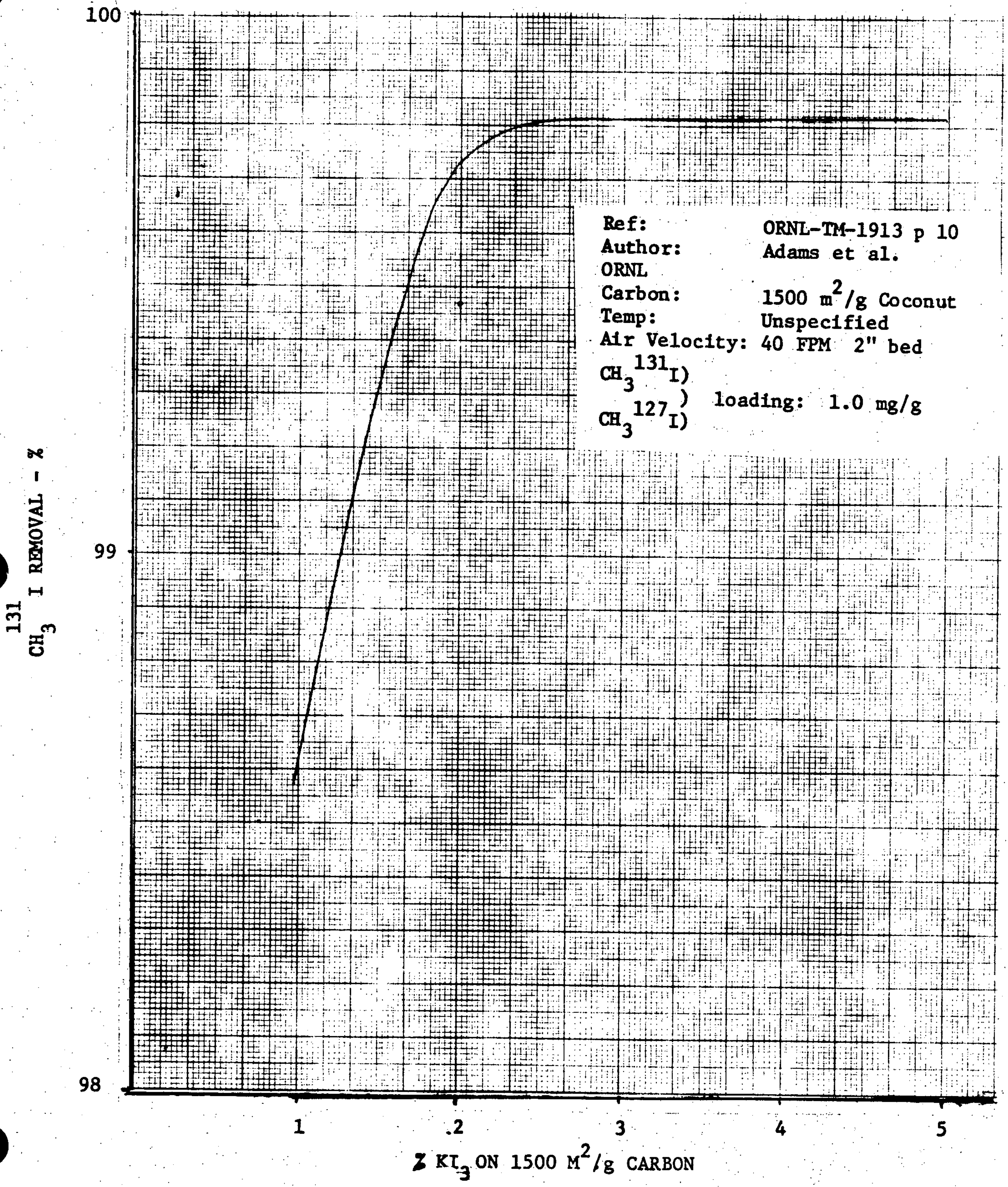
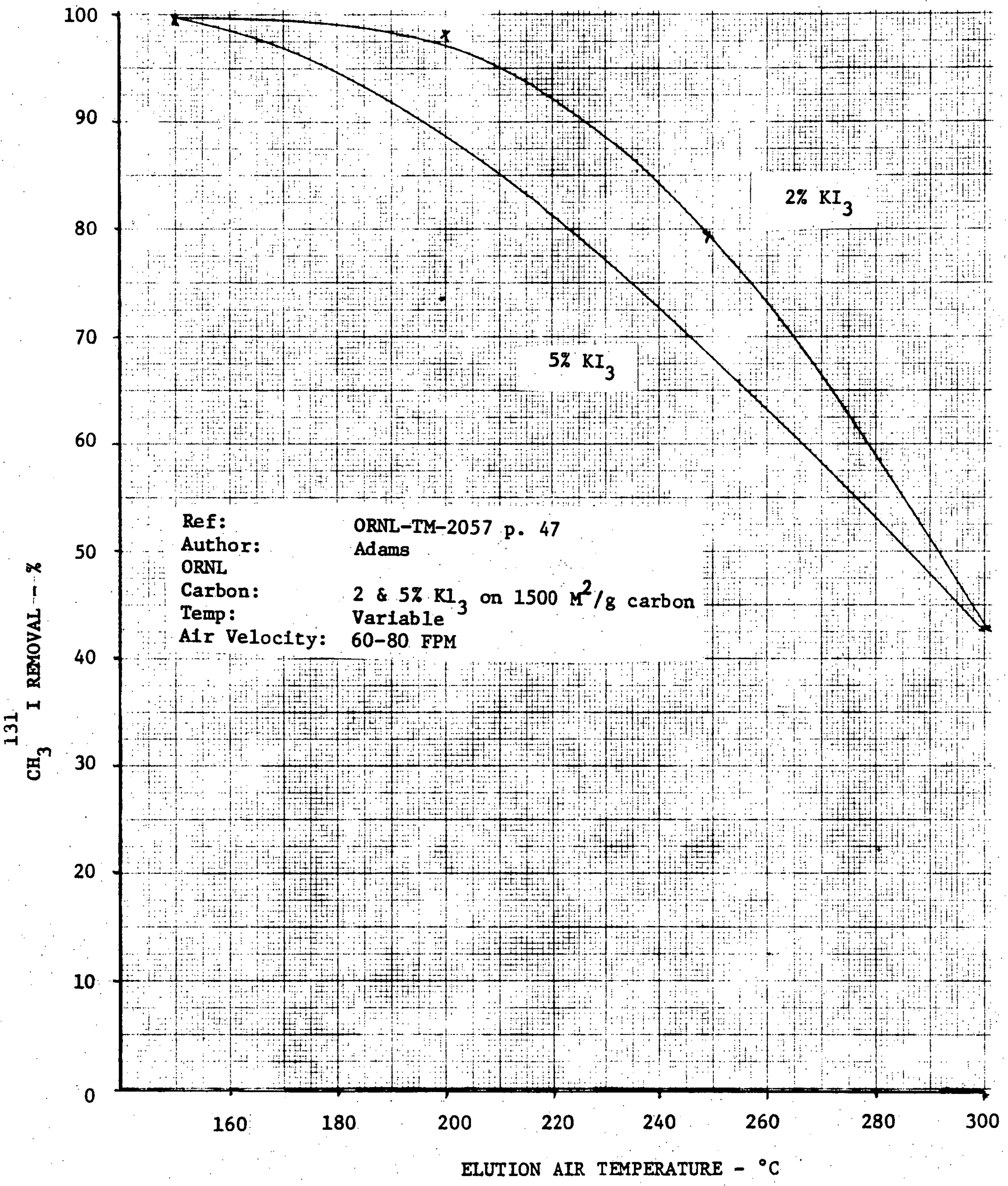

100
99
98
CH3 131 I REMOVAL - %
1
.2
3
4
5
% KI3 ON 1500 M2/g CARBON
Ref: ORNL-TM-1913 p 10
Author: Adams et al.
ORNL
Carbon: 1500 m2/g Coconut
Temp: Unspecified
Air Velocity: 40 FPM 2" bed
CH3 131I)
) loading: 1.0 mg/g
CH3 127I)

FIGURE 33



Ref: ORNL-TM-2057 p. 47
Author: Adams
ORNL
Carbon: 2 & 5% KI_3 on 1500 M^2/g carbon
Temp: Variable
Air Velocity: 60-80 FPM

FIGURE 34

NOTES FOR FIGURES

Figure 4

The 100% RH is listed in the ORNL data as "Relative humidity probability 100%"

Figure 5

The lower curve in this drawing represents conditions where bulk phase condensation was observed in the first half inch of the bed. Total bed depth (1/2" + 1/2" + 1.0") 2".

Figure 6

The 100% RH data were obtained at 27 FPM. At this velocity flooding of the bed is more likely due to entrainment between the carbon grains.

Figure 8

The water adsorption on the two 100% RH data was measured at 135 and 156% by weight. The maximum water adsorption capacity of this carbon at 100% RH from adsorption isotherms is 50-55% weight, thus 2/3 of the water was present in the void volume between the carbon grains not only slowing down diffusion but also increasing stream velocity through the unblocked part of the bed. These numbers also indicate that the bed itself was operated under highly supersaturated conditions.

Figure 10

This carbon shows water loading at 100% RH from H_2O adsorption systems at 30-35%, thus values obtained on indicated relative humidities of 95% and 97% are in fact above 100% and represent conditions of flooding.

Figure 11

This carbon has a H_2O loading of 30-33% of 100% RH. This point indicated at 92% RH is above 100% RH indicating flooding.

Figure 12

This carbon has a H_2O loading of 50-55% by weight at 100% RH. At the two 99% RH points the indicated water adsorption is 143 and 150% by weight. At these H_2) loadings the carbon is flooded.

Figure 13

This carbon has a H_2O loading of 50-55% by weight at 100% RH. The water loading from the ORNL data is:

1st	0.5"	150%	by weight	$CH_3{}^{131}I$	removal	7.47%
2nd	0.5"	126%	by weight	$CH_3{}^{131}I$	removal	10.18% (cum.)
3rd	1.0"	82%	by weight	$CH_3{}^{131}I$	removal	12.72% (")

indicating that the bed is flooded.

Figure 15

In this drawing combined data are presented for MSA 85851, BC 272 and NACAR G601 at only under similar conditions. These carbons are similar both in starting material and method of impregnation. References are NACAR-DWG-4, 28, 30, 25, 13, 14.

Only ORNL data obtained by Messr. Adams and Ackle, are included. Data show efficiency for 2" bed only. Indicates where data are available to show excessive flooding of the carbon bed. No moisture loading is available for the MSA 85851 carbon at the 95 and 100% RH points.

Broken line indicates confined flooding. Solid line shows no flooding and unconfirmed but probable flooding at 95 and 100% RH.

Figure 16

For the efficiency and residence time vapors ploted here the max H_2O content of the MSA 85851 was 65% by weight verses the Approx 55% expected from the H_2O isotherm data.

Figure 17

Personal communication from Dr. D. A. Collins of UKAEA MSA 85851-BC 727 and NACAR G601 carbons are approximately equal in adsorption capacity.

Figure 18

207 B impregnated with 0.5% K1 was prepared in four particle size ranges. The screen sizes are in British Standard Sieves. These correspond to the following mm ranges:

8 x 12 ∿ 2.06 x 1.4 mm
12 x 16 ∿ 1.4 x 1.0 mm
18 x 30 ∿ 0.85 x 0.5 mm
30 x 50 ∿ 0.5 x 0.3 mm

Figure 19

Data are plotted here for carbon indentified as Norit 0.5% KI in pellets 2mm diameter, from Table II of paper #SM-110/60 presented by Dr. J. G. Wilhelm at the IAEA symposium in August 1968 in New York. The data for MSA 85851 were obtained as a personal communication from Mr. Wilhelm. Both carbons are approximately the same particle size. The tests were performed after 20 hours prehumidification. The $CH_3{}^{131}I$ was injected for 20 hours and flow was maintained for 2 additional hours.

Figure 20

Data are shown on three different Norit carbons

0.8 mm ϕ impregnated with 1.0% K1
1.0 mm ϕ impregnated with 1.0% BaI
2.0 mm ϕ impregnated with 0.5% K1

Figure 25

Data obtained by N_2 adsorption at liquid N_2 temperatures Method used Cranston and Inkley. Advances in Satalysis Vol 1X, P. 143.

Based on other data the impregnation has less effect than particle size in the CH_3^{131} removal efficiencies. The process is diffusion controlled thus particle size difference is more prevalent at low residence times.

Figure 27

The water adsorption isotherm is plotted for 207B with 0.5% KI impregnation The curve is typical for H_2O adsorption (∿ shape) on activated carbon at ambient temperature. The single point marks value for the same carbon soaked in water and centrifuged to remove interstitial water. This is a static point air was not passed through the bed.

Figure 28

Activated carbon types commonly used in nuclear and industrial applications were equilibrated both under static and dynamic conditions at 100% RH. Static tests were conducted for 1000 hours contact time. The last 300 hours did not show further increase. The dynamic static tests were conducted for 72 hours.

Figure 29

This curve represents H_2O equilibration of carbon under dynamic conditions at 100% RH; 3.6×10^3 air changes/hour.

Figure 30

These data are on unimpregnated carbon.

Figure 31

These data are shown to emphasize that other factors than isotope exchange can take place in the process. In most cases this can be adsorption or catalytic decomposition.

Figure 33

The carbon used in these experiments is the same as the base material for MSA 85851, NACAR G601 and BC 727. The impregnation was made by water solution of KI and I_2

Figure 34

The data show impregnation of identical base carbon (one commonly used to prepare impregnated carbons) impregnated by 2% and 5% KI_3 from water solution. The duration of the heating period was 4 hours.

BIBLIOGRAPHY

1. Golden, D.M., Walsh, R. and Benson, S.W. J. Am. Chem. Sec. 87 (1965) 4053.

2. Baines, R.H., Kircher, J.F. and Townley, C.W. BMI - 1781 (1966)

3. Barnes, R. M., McFarling, J.L., Kircher, J.F. and Townley, C.W. BMI - 1816 (1967) & BMI - 1829 (1968).

4. Kircher, J.F. & Baines, R.H., Paper # SM 110/21, AREA Symposium on Operating Experience in Treatment of Airborne Radioactive Water . (1968).

5. Mishama, J. BNWL - 319 (1966)

6. Durant, W.S., Milham, R.C., Muhlbrier, R.D., and Peters, A.H., DP - 1071 (1966).

7. Hilliard, R.K. & McCormack, J.W., Int. Symp. on Fission Product Release and Transport CONF - 650407 Vol. 1. p. 588 (1965).

8. Nucl. Safety Program Seminar, Progress Reports ORNL - 3776 (1965) ORNL - 3691 (1964), ORNL - 3843 (1965).

9. Croft, J.F. & Iles, R.S., AEEW-R 172, UKAEA (1962)

10. Hillary, J.J. & Taylor, J.C. TRG - 888 (w) UKAEA (1965).

11. Adams, R.E. et al. ORNL - TM - 1913 (1967)

12. Ackley, R.D. et al. ORNL - 3915 (1966)

13. Adams, R.E. & Browning, W.E. ORNL - 3915 (1966).

14. Browning, W.E. et al. ORNL - 3843 (1965).

15. Collins, D.A., Taylor, L.R., and Taylor, R. TRG - 1300 (w) (1967).

16. Adams, R.E. et al. ORNL - TM - 1291 (1965).

17. Ackley, R.D. et al. ORNL - 3915 (1966)

18. Parker, G.W., Creek, G.E., and Ferrel, A. CONF - 660904 (1967).

19. Ackerman, F.J., Grens, J.Q. CONF - 660904 (1967).

20. Adams, R.E., Ackley, R.D., and Browning, W.E. ORNL - 4040 (1967)

21. Ackley, R.D. & Adams, R.E. ORNL - 4180 (1967).

22. Adams, R.E., Ackley, R.D., Shields, R.P. Paper SM 110/37 IAEA of Ref. 4 (1968).

23. Wilhelm, J.G. Paper SM 110/60 IAEA of Ref. 4 (1968).

BIBIOGRAPHY (Continued)

24. CYAP - 101, Conn. Yankee Atomic Power Co. (1966)

25. Murata, T., & Kamiya, K. Paper # SM 110/1 IAEA of Ref. 4, (1968).

26. Dadillon, J. Paper # SM 110/10 IAEA of Ref. 4. (1968).

27. Adams, R.E. et al. ORNL - TM - 2057 (1967).

28. Brunauer, S. "The Adsorption of Gases and Vapors" Princeton Univ. Press (1945).

29. Adams, R.E. et al. ORNL - 4071 p. 138-139 (1967).

30. Peters, A.H. DP 812 (1962).

31. Rivers, R.D. & Trinkle, J.L. NYD - 3250 - 6 (1966).

32. Tang, I.N. & Castleman, A.W. BNL - 9174 (1965).

33. Jones, L.R. 10th USAEC Conf. (1968).

3.0 CONTAINMENT AIR RECIRCULATION COOLING AND FILTRATION SYSTEM

A DESIGN BASES

Containment Heat Removal Systems

Criterion: Where an active heat removal system is needed under accident conditions to prevent exceeding containment design pressure, this system shall perform its required function, assuming failure of any single active component. (GDC 52)

Adequate heat removal capability for the containment is provided by two separate, full capacity, engineered safety features systems. These are the Containment Spray System and the Containment Air Recirculation Cooling and Filtration System. These systems are of different engineering principles and serve as independent backups for each other.

The Containment Air Recirculation Cooling and Filtration System is designed to recirculate and cool the containment atmosphere in the event of a loss-of-coolant accident and thereby ensure that the containment pressure will not exceed its design value of 47 psig at 271°F (100% relative humidity). Although the water in the core after a loss-of-coolant accident is quickly subcooled by the Safety Injection System, the Containment Air Recirculation Cooling and Filtration System is designed on the conservative assumption that the core residual heat is released to the containment as steam.

Any of the following combinations of equipment will provide sufficient heat removal capability to maintain the post-accident containment pressure below the design value, assuming that the core residual heat is released to the containment as steam.

1) All five containment cooling fans

2) Both containment spray pumps (and one of the two spray valves in the recirculation path).

3) Three of the five containment cooling fans and one containment spray pump.

Inspection of Containment Pressure-Reducing Systems

Criterion: Design provisions shall be made to extent practical to facilitate the periodic physical inspection of all important components of the containment pressure-reducing systems, such as pumps, valves, spray nozzles, torus, and sumps. (GDC 58)

Design provisions are made to the extent practical to facilitate access for periodic visual inspection of all important components of the Containment Air Recirculation Cooling and Filtration System.

Testing of Containment Pressure-Reducing Systems Components

Criterion: The containment pressure-reducing systems shall be designed to the extent practical so that components, such as pumps and valves, can be tested periodically for operability and required functional performance. (GDC 59)

The Containment Air Recirculation Cooling and Filtration System is designed to the extent practical so that the components can be tested periodically, and after any component maintenance, for operability and functional performance.

The air recirculation and cooling units, and the service water pumps, which supply the cooling units, are in operation on an essentially continuous schedule during plant operation, and no additional periodic tests are required.

Testing of Operational Sequence of Containment Pressure-Reducing Systems

Criterion: A capability shall be provided to test initially under conditions as close as practical to the design and the full operational sequence that would bring the containment pressure-reducing systems into action, including the transfer to alternate power sources. (GDC 61)

Means are provided to test initially to the extent practical the full operational sequence of the Air Recirculation System including transfer to alternate power sources.

Inspection of Air Cleanup Systems

Criterion: Design provisions shall be made to the extent practical to facilitate physical inspection of all critical parts of containment air cleanup systems, such as, ducts, filters, fans and damper. (GDC 62)

Access is available for periodic visual inspection of the Containment Air Recirculation Cooling and Filtration System components.

Testing of Air Cleanup Systems Components

Criterion: Design provisions shall be made to the extent practical so that active components of the air cleanup systems, such as fans and dampers, can be tested periodically for operability and required functional performance. (GDC 63)

The charcoal filters of the Filtration System are bypassed during normal operation by closed butterfly valves. The valves in a non-operating unit can be periodically tested by actuating the controls and verifying deflection by instruments in the Control Room. Since the fans are normally in operation, no additional periodic fan tests are necessary.

Testing Air Cleanup Systems

Criterion: A capability shall be provided to the extent practical for in situ periodic testing and surveillance of the air cleanup systems to ensure (a) filter bypass paths have not developed and (b) filter and trapping materials have not deteriorated beyond acceptable limits. (GDC 64)

Representative sample elements in each of the activated charcoal filter plena will be removed periodically during shutdowns and tested on the site to verify their continued efficiency. After reinstallation the filter units will be tested in place by aerosol injection to determine integrity of the flow path.

Testing of Operational Sequence of Air Cleanup Systems

Criterion: A capability shall be provided to test initially under conditions as close to design as practical, the full operational sequence that would bring the air cleanup systems into action, including the transfer to alternate power sources and the design air flow delivery capability. (GDC 65)

Means are provided to test initially under conditions as close to design as is practical the full operational sequence that would bring the Containment Air Recirculation Cooling and Filtration System into action, including transfer to the emergency diesel-generator power source.

Performance Objectives

The Containment Ventilation System, Section 5, which all of the components of the Containment Air Recirculation Cooling and Filtration System (with the exception of the charcoal filters) are a part of, is designed to remove the normal heat loss from equipment and piping in the reactor containment during plant operation and to remove sufficient heat from the reactor containment, following the initial loss-of-coolant accident containment pressure transient, to keep the containment pressure from exceeding the design pressure. The fans and cooling units continue to remove heat after the loss-of-coolant accident and reduce the containment pressure close to atmospheric within the first 24 hours.

A second function of the Containment Air Recirculation Cooling and Filtration System is to remove fission products from the containment atmosphere should they be released in the event of an accident.

The filtration capacity of the system is sufficient to reduce the concentration of fission products in the containment atmosphere following a loss of reactor coolant to levels ensuring that the two hour and 30 day thyroid doses will be limited to within the guidelines of 10 CFR 100 limits. Details of the site boundary dose calculation are given in Section 12 of the PSAR and Supplement 1, Item 16 (E-7.2).

The air recirculation filtering capacity used to satisfy the design basis is determined for the following conditions:

a) Containment leak rate of 0.1% per day.

b) Conservative meteorology corrected for building wake effects.

c) Fission product release to the containment per TID 14844 at a power level of 3216 MWt. This assumes no credit for safety injection in limiting fission product release.

d) Partial effectiveness of the filtration equipment in reducing the concentration of radioactive iodine in the containment atmosphere. Two of the five installed charcoal filter banks are assumed inoperative. The remaining three banks are assumed to remove 90% of the inorganic form iodine and to undergo isotopic exchange equilibrium with 50% of the organic form iodine in the containment atmosphere in each pass through the filters.

e) Partial effectiveness of the filtration equipment. This assumes two of the five installed charcoal filter units are unavailable at the time of the loss of coolant.

In addition to the design basis specified above, the following objectives are met to provide the engineered safety features functions:

a) Each of the five fan-cooler units is capable of transferring heat at the rate of 21,200 Btu/sec. (76.32×10^6 Btu/hr) from the containment atmosphere at the post-accident design conditions, i.e., a saturated air-steam mixture at 47 psig 271°F. This heat transfer rate is that assigned to the fan-cooler units in the analysis of containment and related heat removal system capability in Supplement 1.

The establishment of basic heat transfer design parameters for the cooling coils of the fan-cooler units, and the calculation by computer of the overall heat transfer capacity are discussed in Supplement 1. Among the topics covered are selection of the tube side fouling factor, effect of air side pressure drop, effect of moisture entrainment in the air steam mixture entering the fan-coolers, and calculation of the various air side to water side heat transfer resistances.

b) In removing heat at the design basis rate, the coils are capable of discharging the resulting condensate without impairing the flow capacity of the unit and without raising the exit temperature of the service water to the boiling point. Since condensation of water from the air-steam mixture is the principal mechanism for removal of heat from the post-accident containment atmosphere by the cooling coils, the coil fins will operate as wetted surfaces under these conditions. Entrained water droplets added to the air-steam mixture, such as by operation of the containment spray system, will therefore have essentially no effect on the heat removal capability of the coils.

c) Each of the five air handling units is equipped with a moisture separator and high efficiency particulate air (HEPA) filters rated for full unit flow. The moisture separators are capable of removing 99. % of moisture droplets 1 micron or larger in diameter, and the HEPA filters will retain 99.97% of incident 0.3μ particles (DOP test) under dry conditions. Together, the separators and filters will prevent the ingress of liquid and solid aerosol material to the charcoal filters as well as reduce the radioactivity of the containment atmosphere associated with these aerosols. The water removal capability of the units is evaluated as part of the charcoal filter analysis.

d) Each of the five air handling units is capable of supplying air to separate carbon-bed filter units following an accident for fission product iodine removal. The design flow rate through each air handling unit is 65,000 cfm. The design flow rate through the charcoal filter bank in each unit is 7,440 cfm, while the remainder of the air handling unit flow bypasses the filter bank. The total flow capacity of the unit in its post accident recirculation mode is utilized in condensing steam (as noted in item (a) above) and insuring bulk mixing of the containment atmosphere, whereas the partial flow which is diverted through the charcoal beds satisfies the iodine activity reduction requirements of the system.

In addition to the above design bases, the Containment Air Recirculation Cooling and Filtration System is designed to operate at the post accident conditions at 47 psig and 271°F for three hours, followed by operation at 20 psig, 219°F for an additional 21 hours, and then for an indefinite period at 5 psig, 152°F. All conditions imply saturated air-steam mixtures at the pressure indicated. The design is such as to withstand also the effects of containment spray, radiation and seismic loadings (per Class I criteria) without loss of function.

All components are capable of withstanding or are protected from differential pressures which may occur during the rapid pressure rise to 47 psig in ten (10) seconds.

Portions of other systems which share functions and become part of this containment cooling system when required are designed to meet the criteria of this section. Neither a single active component failure in such systems during the injection phase nor an active/passive failure during the recirculation p phase will degrade the design heat removal capability of containment cooling.

Where portions of these systems are located outside of containment, the following features are incorporated in the design for operation under post-accident conditions:

a) Means for isolation of any section

b) Means to detect and control radioactivity leakage into the environs, to the limits consistent with guidelines set forth in 10 CFR 100.

B SYSTEM DESIGN AND OPERATION

The Flow Diagram of the Containment Air Recirculation Cooling and Filtration System is shown in Supplement 5, Item 2.

Individual system components and their supports meet the requirement for Class I (Seismic) structures and each component is mounted to isolate it from fan vibration.

Containment Cooling System Characteristics

The air recirculation system consists fo five 20% capacity air handling units, each including a motor, fan, cooling coils, moisture separator, roughing filters and HEPA filters, duct distribution system, instrumentation and controls. The units are located on the intermediate floor between the containment wall and the primary compartment shield walls. In addition, each of the five air-handling units is equipped with an activated charcoal filter unit, normally isolated from the main air recirculation stream. Part of the air flow (air-steam mixture) is bypassed through the charcoal filter units to remove volatile iodine following an accident.

At the maximum post accident design pressure and atmospheric density (47 psig, 0.175 lb/ft^3) the fans will operate at reduced speed, delivering approximately 25,000 cfm. The fans are direct driven, centrifugal type, and the coils are plate fin tube type. Each air handling unit is capable of removing 76.32×10^6 Btu/hr from the containment atmosphere under accident conditions. 2000 gpm of service (cooling) water is supplied to each unit during accident conditions. The design maximum river water inlet temperature is 85°F which results in a maximum outlet temperature of 161°F.

Air operated, tight closing 125 lb USAS butterfly valves isolate any inactive air handling unit from the duct distribution system. Duct work distributes the cooled air to the various containment compartments and areas. During normal operation, the flow sequence through each air handling unit is as follows: Moisture separator, cooling coils, roughing filters, HEPA filters, fan, discharge header.

In the event of an accident, the flow sequence would be the same except that the fan discharge would be automatically diverted by air operated butterfly valves to a compartment containing the charcoal filters before entering the discharge header for distribution.

Actuation Provisions

The butterfly valves used to route air flow through the charcoal filters have only two positions, full open and full closed. These valves are air operated and spring loaded. Upon loss of control signal or control air, the spring actuates the valve to the accident position (fail-safe operation).

Upon either manual or automatic acutation of the safety injection safeguards sequence, the butterfly valves are tripped to the accident position. Accident position is also the "fail-safe position."

Redundant electrically operated three-way solenoid valves are used as each butterfly valve to control the instrument air supply (control air). These valves are arranged so that failure of a single solenoid valve to respond to the accident signal will prevent actuation of the butterfly valve to the accident position (fail-safe operation).

The containment pressure is sensed by six separate pressure transmitters located outside the containment. Containment pressure is communicated to the transmitters through three 1" stainless steel lines penetrating the containment vessel. A high containment pressure signal automatically acutates the safety injection safeguard sequence which trips the valves to the accident position.

The fans are part of the engineered safety features and either all five, or at least three of five fans will be started after an accident, depending on the availability of emergency power. Reference is made to Section 8 and Supplement 1.

Overload protection for the fan motors is provided at the switchgear by overcurrent trip devices in the motor feeder breakers. The breakers can be operated from the control room and can be reclosed from the control room following a motor overload trip.

Redundant flow switches in the system, operating both normally and post-accident, indicate whether air is circulating in accordance with the design arrangement. Abnormal flow alarms are provided in the control room.

Flow Distribution and Flow Characteristics

The location of the distribution ductwork outlets, with reference to the location of the air handling unit return inlets, ensures that the air will be directed to all areas requiring ventilation before returning to the units.

In addition to ventilating areas inside the periphery of the shield wall, the distribution system also includes two branch ducts located at opposite extremes of the containment wall for ventilating the upper portion of the containment. These ducts are provided with nozzles and extend upward along the containment wall as required to permit the throw of air from nozzles to reach the dome area and assure that the discharge air will mix with the atmosphere.

The air discharge inside the periphery of the shield wall will circulate and rise above the operating floor through openings around the steam generators where it will mix with air displaced from the dome area. This mixture will return to the air handling units through floor grating located at the operating floor directly above each air handling unit inlet. The temperature of this air will be essentially the ambient existing in the containment vessel.

The steam-air mixture from the containment entering the moisture separator during the accident will be at approximately 271°F and have a density of 0.175 pounds per cubic foot. The purpose of the moisture separator is to remove the entrained moisture. The fluid will therefore leave the moisture separator and enter the cooling coil at approximately 271°F and saturated (100% R.H.) condition. Part of the water vapor will condense on the cooling coil, and the air leaving the unit will be saturated at a temperature slightly below 271°F.

The fluid will remain in this condition as it flows through the roughing filter, HEPA filter and into the fan, but will pick up some sensible heat from the fan and fan motor before flowing through the charcoal filters and into the distribution header. This sensible heat will increase the dry-bulb temperature slightly above 271°F and will decrease the relative humidity slightly below 100%.

With a flow rate of 25,000 cfm from each of the three fans under accident conditions the average recirculation rate of the 2.61×10^6 ft^3 containment atmosphere is 1.72 containment volume per hour.

Charcoal Filter High Temperature Detection and Dousing System

The five charcoal filter units are provided with high-temperature detectors, and associated alarms in the control room. Each charcoal filter unit is also provided with a spray system for water dousing, upon a signal of high temperature.

Capability for detecting and alarming the presence of fires and localized hot spots in the charcoal filters is provided by a system of temperature switches. Each charcoal filter plenum (containing one bank of 14 absorber units) is provided with temperature switches uniformly distributed to alarm in case of excessive filler temperature in any part of the bank. The temperature switches are set to close at 400°F, (which is significantly below the charcoal ignition temperature of 680°F) and are wired in parallel to a common alarm in the control room. Thus closing of a single switch will actuate the alarm to indicate a high temperature condition in the filter plenum.

The water dousing system provided with each charcoal filter plenum is designed to drench the absorbers thoroughly in the extremely unlikely event of a charcoal fire during the post-accident recovery. Water for this system is obtained from the main headers of the containment spray system through a separate 2 inch stainless steel line to each filter plenum. There are two normally closed motor operated valves in parallel in each 2 inch line.

The Containment Spray System is automatically actuated and will be running in the event of a loss-of-coolant accident (injection phase). In the event of a high temperature alarm in a filter unit, the operator manually initiates filter dousing by actuating the parallel-connected isolation valves for each filter assembly. Because of the piping arrangement either of the two spray pumps can be used to feed the dousing lines. The dousing flow (approximately 100 gpm) is sized to completely wet the charcoal and remove the decay heat of the absorbed iodine, thereby preventing heating to the ignition temperature. The system is designed so containment spray at slightly reduced flow can continue simultaneously with filter dousing.

During the recirculation phase of core cooling, operation of the dousing system is the same as above except that water to the spray headers is supplied from the discharge of the residual heat removal heat exchangers.

Cooling Water for the Fan Cooler Units

The cooling water requirements for all five fan cooling units during a major loss of primary coolant accident and recovery are supplied by two of the three nuclear service water pumps.

The cooling water discharges from the cooling coils to the discharge canal and is monitored for radioactivity by routing a small bypass flow from each unit through a common radiation monitor. Upon indication of radioactivity in the effluent, each cooler discharge line is monitored individually to locate the defective cooling coil, which when identified would remain isolated; operation would continue with the remaining units. The service water system pressure at locations inside the containment is 15 to 20 psig, which is below the containment design pressure of 47 psig. However, since the cooling coils and service water lines are completely closed inside the containment, no contaminated leakage is expected into these units.

Local flow and temperature indication is provided outside containment, for service water flow to each cooling unit. Abnormal flow alarms are provided in the control room.

During normal plant operation, flow through the cooling units is throttled for containment temperature control purposes by a valve on the common discharge header from the cooling units. Two independent, full flow, isolation valves open automatically in the event of a high containment pressure signal or safety injection signal to bypass the control valve. Both valves fail in the open position upon loss of air pressure and either valve is capable of passing the full flow required for all five fan cooling units.

Environmental Protection

All system control and instrumentation devices required for containment accident conditions are located to minimize the danger of control loss due to missile damage. Flow switches in the ductwork system, operating both normally and post-accident, indicate whether air is circulating in accordance with the design arrangement. Abnormal flow alarms are provided in the control room.

All fan parts, valve shaft and disc seating surfaces and ducts in contact with the containment fluid are protected against corrosion. The fan motor enclosures, electrical insulation and bearings are designed for operation during accident conditions.

All of the air handling units are located on the intermediate floor between the Containment Vessel and the primary compartment shield wall. The distribution header and service water cooling piping are also located outside the shield wall. This arrangement provides missile protection for all components.

Components

Moisture Separators

The moisture separators are designed to remove a minimum of 99.9% of the entrained water in the air-steam entering the air handling units following a loss-of-coolant accident. With an air entrained moisture content of 0.35 lb $H_2O/1000\ ft^3$ the water flow rate entering the moisture separator section is approximately 23 lb/min, and the moisture separator effluent has essentially zero moisture content.

Each bank is designed for horizontal air flow and is composed of forty (40) elements. Each element or separator is 24 in. x 25 in. x 2 in. (minimum) thick and is mounted in a steel support frame.

A steel drain trough is incorporated for each horizontal tier of separators to collect and remove the water that is recovered from the air stream. Further, the design enables the separators to be removed from the upstream side of the support frame.

In order to prevent the bypass of air around the bank, air-tight seals are provided between the floor, walls, plenum, and around the perimeter of each moisture separator. The tight seal is accomplished by gaskets, adhesive, and pressure-sealing tape, all of which can withstand a temperature of 300°F. The thickness of the gaskets is 1/4 in. for the separator elements and 3/8 in. for the perimeter sealing of the support frame; and they do not extend into the media area when installed.

The moisture separator elements are of fire resistant construction, and consist of mats of Teflon yarn wrapped over stainless steel reinforcing wire. Non-stainless steel parts used in the construction are protected against corrosion by painting with one (1) three-mil shop coat of Carbo Zinc No. 11 or equal. The separator frames are fabricated of Type 304L stainless steel, with welded joints.

Inlet baffles are provided on the upstream side of the separator sections to prevent impingement of the entrained moisture against the separator elements. These are fabricated of 304L stainless steel.

Roughing Filters

The roughing filters prolong the life of the HEPA filters by removing the large particles from the air stream before it contacts the high efficiency filters. These are efficient for removing large particles. Under normal air flow, they offer a resistance to air flow of 0.2 inches of water.

As in the case for all components of the air handling recirculating system, the bank will be designed for horizontal air flow. The bank contains forty (40) filters, each of which has dimensions of 24 in. x 24 in. x 2 in. thick.

All other details of the mounting frame, sealing and materials of construction, other than the filters themselves, are the same as described for the same demister.

The filter is of fire resistant construction with the media composed of a glass fiber mat reinforced with stainless steel wire cloth.

HEPA (absolute) Filters

The high efficiency particulate air (HEPA) filters are capable of 90% removal efficiency for 0.3μ particles at the post accident design conditions. All materials of construction of these filters are compatible with the sodium hydroxide/boric acid solution in the post accident environment.

The filter media is made of glass fiber with asbestos and can withstand the incident ambient steam/air temperature conditions and 100% relative humidity. Filter frames are made of stainless steel, and asbestos separators resistant to moisture and high temperature are used.

Fan-Motor Units

The five containment cooling fans are of the centrifugal, non-overloading, direct drive type.

Each fan can provide a minimum flow rate of 25,000 cfm when operating in the accident environment (0.175 lb/ft^3 density, a containment pressure of 47 psig, and temperature of 271°F).

The reactor containment fan cooler motors are Westinghouse, totally enclosed water cooled, induction type, 3 phase, 60 cycle, two speed, 440 volt Thermalastic insulated motors. Significant motor details are as follows:

a. Insulation - Class F (nema rated total temperature 155°C) Thermalastic. Basic structure high turn to turn and coil to ground insulation. It is impregnated and coated to give a homogeneous insulation system which is highly impervious to moisture. Internal leads and the terminal box-motor interconnection are given special design consideration to assure that the level of insulation matches or exceeds that of the basic motor system. At incident ambient and load conditions the motor insulation hot spot temperature is not expected to exceed 107°C.

b. Heat Exchanger

An air to water, heat exchanger is connected to the motor to form an entirely enclosed cooling system. Air movement is through the heat exchanger and is returned to the motor. A vent valve permits incident ambient (increasing containment pressure) to enter the motor air system so the bearings will not be subjected to differential pressure. It also assumes pressure equalization as the containment pressure is reduced by the containment cooling systems. Water connections are welded throughout and supply and discharge are common with the containment cooler water system, i.e., supplied from the nuclear service water header. The drain will be piped to the containment cooler drain system.

c. Bearings

The motors are equipped with high temperature grease lubricated ball bearings as would be required if the bearings were subjected to incident ambient temperatures. Continuous bearing monitoring is provided which will alarm in the control room.

Conduit (Connection) Box

The motor leads are brought out of the frame through a seal and into a cast iron, sealed explosion proof type of conduit box.

Factory Tests

In addition to the usual quality control tests which are performed to give assurance that the motors meet design specifications, special tests have been performed to demonstrate that insulation margins are built in as expected. The completely wound stators have been given a special high potential test to ground. The stators were immersed in water, meggered and given a high potential test while immersed. After passing the water tests, the motor was baked and given a final coating dip. The stator and rotor were then again baked and coated.

Development Tests

The Westinghouse system of insulation has been subjected to extensive testing including formette tests and data have been recorded which show ample life of the insulation. Test data at 200°C, 180°C and 160°C give an average life of 1365 hrs., 3948 hrs., and 28616 hrs., respectively and a minimum life of 1248 hours., 2688 hrs., and 24690 hrs., respectively.

Charcoal Filters

The charcoal filters are fabricated with stainless steel frames filled with impregnated, activated charcoal. The cell construction insures compacted carbon beds of uniform density and thickness.

The design flow rate through each charcoal filter bank is 7,440 cfm, at a face velocity of 50 fpm. The bed thickness of 2 inches provides a superficial residence time of 0.2 sec. Under the design conditions of temperature, pressure, and humidity, and with moisture uptake limited to less than 1 gram of water per gram of dry charcoal the expected penetration of incident I_2 vapor is less than 0.1%. Performance objectives do not require that this capability be achieved. Instead, recirculation capacity is such that 10% bypass flow through imperfect seating of the filter in its frame, gasket deterioration or other causes can be accepted. With respect to organic iodine vapor, the probability of isotopic exchange at these conditions is about 0.80 (refer to Section 2). The performance objectives are met if

50% of the incident organic iodides bypass the bed or otherwise penetrate the filter without undergoing exchange. As a further measure of conservatism, the isotopic makeup of the 50% which undergoes exchange is assumed to reach equilibrium with the bulk (average) iodine inventory of the filter bed. In this single theoretical stage treatment, no advantage is taken of the favorable gradient which places the highest concentration of radioactive iodine near the leading face of the filter and causes the effluent vapor to tend toward equilibrium with the less radioactive iodine near the outlet face.

Each of the five charcoal filter units consists of an airtight plenum containing a single bank of charcoal filter cells. Air flow enters the plenum through one end, passes through the charcoal filter bank, and is exhausted from the plenum through ductwork into the main distribution header.

The individual filter cells are of the "flat-bed" type of construction, with two 2-inch thick horizontal charcoal elements separated by a 2-inch air gap. The sides and back of the cell are enclosed by solid (unperforated) stainless steel sheet metal; the larger (horizontal) surfaces are enclosed by perforated stainless steel sheets. An unperforated stainless steel sheet seals the front edge; this sheet is slightly larger than the basic filter dimensions to provide flanges for clamping in the mounting frame. Several rectangular slots are cut in the front face to permit air flow. Each filter cell provides approximately 12.3 sq. ft. of active surface area for air flow (both elements) and contains approximately 2 cu. ft. of charcoal. The charcoal used is MSA type 85851 or equivalent.

During operation, air flows vertically downward through the top surface of the filter and upward through the bottom surface, enters the air space between the two charcoal elements, and is discharged through the slots in the front face.

Each filter bank consists of 12 cells. The downstream mounting racks arrangement permits removal of individual cells from the side of the plenum.

The duct connections are flexible to prevent transmissions of duct vibration to the filter units.

The filter units are designed to withstand the maximum differential pressure developed by the fans under accident conditions without developing internal leaks or being dislodged from their frame seals.

Charcoal Filter Dousing System

The spray water dousing system inside the charcoal filter plenams is of stainless steel and copper construction. This system provides three individual injection lines, terminating in 3/8 inch brass nozzles, which spray into the air space between each pair of vertically adjacent adsorber units. The nozzles discharge horizontally, to assure complete wetting of both upper and lower adsorber surfaces. The design flow of approximately 1/3 gpm per nozzle results in a design pressure drop of 30 psi. The nozzle orifice is not subject to clogging with particle size less than .045 inches.

Cooling Coils

The coils are fabricated of copper plate fins vertically oriented on copper tubes. The heat removal capability of the cooling coils is 76.32×10^6 Btu/hr per air handling unit at saturation conditions (271°F, 47 psig).

The design internal pressure of the coil is 150 psig at 300°F and the coils can withstand an external pressure of 70.5 psig at a temperature of 300°F without damage.

Each recirculating unit will consist of ten (10) coil units mounted in two banks of five (5) coils high. These banks will be located one behind the other for horizontal series air flow, and the tubes of the coil will be horizontal.

Each coil will be 37 1/4 in. high x 15 in. wide x 117 in. long with 108 finned tubes each being 107 in. long. The tubes will be on a 2 1/4 in. triangular pitch, thereby giving six (6) rows of tubes in the horizontal direction and 18 rows of tubes in the vertical direction. Cooling water flow will be double circuited (54 tubes per circuit) and tube supports will be provided on 15 in. center lines to permit free expansion and contraction of the tubes.

For normal operation, 7 fins/inch are required to remove 2,000,000 Btu/hr using 108 tubes.

Local flow and temperature indication of service water are provided at each air handling unit. Alarms indicating abonrmal service water flow, and radioactivity are provided in the control room.

The coils are provided with drain pans and drain piping to prevent flooding during accident conditions. This condensate is drained to the Containment Sump.

Ducting

The ducts are designed to withstand the sudden release of reactor coolant system energy and energy from associated chemical reactions without failure due to shock or pressure waves by incorporation of dampers along the ducts which open at slight overpressure, 1.0 psi. The ducts are designed and supported to withstand thermal expansion during an accident.

Where flanged joints are used, joints are provided with gaskets suitable for temperatures to 300°F.

Ducts are constructed of corrosion resistant material.

Butterfly Valves

The spring loaded air operated valves are tight sealing when closed. This prevents leakage of air into the charcoal filter compartment during normal operation thereby preventing charcoal deterioration. These values fail to the open position to assure flow through the charcoal filters during the accident condition.

Electrical Supply

Details of the normal and emergency power sources are presented in Section 8.

C DESIGN EVALUATION

Range of Containment Protection

The Containment Air Recirculation Cooling and Filtration System provides the design heat removal capacity and the design iodine removal capability for the containment following a loss-of-coolant accident assuming that the core residual heat is released to the containment as steam. The system accomplishes this by continuously recirculating the air-steam mixture: 1) through coiling coils to transfer heat from containment to service water, and 2) through activated charcoal filters to transfer elemental iodine and methyl iodide to the filters from the air-steam mixture.

Any of the following combinations of equipment will provide sufficient heat removal capability to maintain the post-accident containment pressure below the design value assuming that the core residual heat is released to the containment as steam.

1) All five containment cooling fans

2) Both containment spray pumps (and one of the two spray valves in the recirculation path).

3) Three of the five containment cooling fans and one containment spray pump.

System Response

The starting sequence of the last of the five containment cooling fans (at design conditions five of the fans and two of the nuclear service water pumps operate during normal power operations for containment ventilation) and the related emergency power equipment are designed so that delivery of the minimum required air flow to the charcoal filters and cooling water flow is reached in 58 seconds. In the analysis of the containment pressure transient, Section 14.3, a delay time of 60 seconds was assumed.

The starting sequence is:		Seconds
a)	Initiation of safety injection signal, including instrument lag.	1
b)	Starting of diesel generators	19
c)	Starting of last containment cooling fan	38
	Total	58

The valves are actuated to safeguards position by the safety injection signal.

Single Failure Analysis

A failure analysis has been made on all active components of the system to show that the failure of any single active component will not prevent fulfilling the design function. This analysis is summarized in Table 1.

The analysis of the loss-of-coolant accident presented in Section 12 and Item 16 of Supplement 1 is consistent with the single failure analysis.

Loss of a fan motor in a unit should not result in ignition of the charcoal. Ignition should be prevented by backflow induced by the operating fans. If an increase in the charcoal filter temperature were to occur the high temperature detectors would initiate an alarm and the operator would cause the affected bank to be sprayed.

Reliance on Interconnected Systems

The Containment Air Recirculation Cooling and Filtration System is dependent on the operation of the electrical and service water systems. Cooling water to the coils is supplied from the service water system. Three nuclear service water pumps are provided, only two of which are required to operate during the post-accident period.

Shared Function Evaluation

Table 2 is an evaluation of the main components which have been discussed previously and a brief description of how each component functions during normal operation and during the accident.

Reliability Evaluation of the Fan Cooler Motor

The basic design of the motor and heat exchanger as described herein is such that the incident environment is prevented, in any major sense, from entering the motor winding or when entering in a very limited amount (equalizing motor interior pressure) the incoming atmosphere is directed to the heat exchanger coils where moisture is condensed out. If some quantity of moisture should pass through the coil, the changed motor interior environment would "clean up" in that interior air continually recirculates through the heat exchanger.

It will be noted that the motor insulation hot spot temperature is not expected to exceed 107°C even under incident conditions. Considering that rated life could be expected with a continuous hot spot of 155°C, using the industry accepted 10 degree rule (life is doubled for every 10°C drop in temperature) the life expectancy would exceed by many times the expected life of motors applied elsewhere in the plant, even if the incident temperatures were experienced on a continuous basis.

During the lifetime of the plant, these motors perform the normal heat removal service and as such are only loaded to approximately 120-150 HP.

Motor insulation hot spot is expected to be from 15 to 20°C below design level or approximately 90°C with cooling water at maximum summer temperature. In summary, practically none of the insulation life due to thermal aging is used up in normal service and at incident loading, the motor insulation should have greater than normal life. Incident high temperature, moisture and load conditions last only a few hours.

The bearings are designed to perform in the incident ambient temperature conditions. However, it will be noted that the interior bearing housing details are cooled by the heat exchanger. It is expected that bearing temperatures would not exceed 125°C by any significant amount even under incident conditions.

The insulation has high resistance to moisture and tests performed indicate the insulation system would survive the incident ambient moisture condition without failure. The heat exchanger system of preventing moisture from reaching the winding is therefore a design margin. In addition, it will be noted that at the time of the postulated incident, the load on the fan motor would increase, internal motor temperature would increase, and would, therefore, tend to drive any moisture if present, out of the winding. Additionally, the motors are furnished with insulation margin beyond the operating voltage of 440 V.

Following the incident rise in pressure a rather slow rise as far as equalizing pressure in the small volumes of the motor-heat exchanger is concerned, it is not expected that there will be significant mixing of the motor (closed system) environment and the containment ambient.

All hardware used in connection with the motor and heat exchanger is corrosion resistant as an additional margin.

The heat exchanger has been designed using a very conservative fouling factor. However, if surface fouling cut the capability of the heat exchanger by one-half, the motor would still have a normal life expectancy, even under incident conditions.

To prove the effectiveness of the heat exchanger in inhibiting large quantities of the steam air mixture from impinging on the winding and bearings, a full scale motor of the exact same type as described, is being subjected to prolonged exposure of accident conditions. The test will expose the motor to a steam air mixture as well as boric acid and alkaline spray at 80 psig and saturated temperature conditions. Insulation resistance, winding and bearing temperature, relative humidity, voltage and current as well as heat exchanger water temperature and flow will be recorded periodically during the test.

Following the test the motor will be disassembled and inspected to further assure that the unit has performed as designed.

D INSPECTION AND TESTING

Inspection

Access is available for visual inspection of the containment fan-cooler and recirculation filtration components including fans, cooling coils, butterfly valves, filter units and ductwork. Provision has been made for ready removal of a section of the filter banks for inspection and testing.

Testing

Component Testing

The HEPA filters used in the containment fan cooler system are specified to operate in the post-accident containment environment. Each filter is subjected to standard manufacturer's efficiency and production tests prior to shipment.

These include flow resistance tests and the standard Efficiency Penetration test requiring that penetration does not exceed 0.03 percent for 0.3 micron diameter homogeneous dioctylphthalate (DOP) particles.

Evaluation tests are performed on sample filters constructed from the filter medium to demonstrate retention of strength under wet conditions as follows:

(1) The filter is exposed to a flow of wet steam and water spray in a test facility which will simulate the actual filter installation. The water is injected ahead of the filter with a nozzle designed to produce a fine spray. Free (unentrained) moisture will be removed by means of a moisture separator upstream of the filter but no provision will be made for removal of entrained moisture entering the filter.

(2) Following the wet flow test in (1) above, the filter will be dried and tested to demonstrate that its resistance to flow has not significantly increased.

(3) Following test (2) above, the filter will be subjected to the NBS Dust Loading Test followed by an Ultimate Strength Test with the deposited dust still on the filter.

Only filters of a type which have been certified to have passed these tests are accepted for initial use or replacement in the fan coolers application.

Any of the activated charcoal filter absorbers in the air handling units can be removed and tested periodically for effectiveness in removing elemental and methyl iodine forms. In addition, periodic, inplace testing of the filtration assemblies will be made by injection of a freon aerosol in the air stream at the filter inlet to verify the leak-tightness of individual filter elements and their frame seals.

The butterfly valves on each air handling unit can be operated periodically to assure continued operability. The degree of leak tightness of the valves will be established by test at the time of installation.

System Testing

Each fan cooling unit will be tested after installation for proper flow and distribution through the duct distribution system. Four of the fan cooling units are used during normal operation. (Five will only be required for normal operation at design conditions i.e., when the service water inlet temperature is 85°F and this condition is expected to exist only for relatively short periods, if at all). The fan not in use can be started from the control room to verify readiness. The butterfly valves directing flow through the charcoal filter banks will be tested only when the fan is not running.

After reinstallation, following testing, the filter charcoal units will be tested in place by aerosol injection to determine integrity of the flow path.

Operational Sequence Testing

A further test will demonstrate proper transfer and sequencing of the fan motor supplies from the diesel generators in the event of loss of power. A test signal will be used to demonstrate proper valve motion and fan starting prior to installation of the charcoal filters. This test will verify proper functioning of the vane-switch flow indicators.

TABLE 1

SINGLE FAILURE ANALYSIS - CONTAINMENT AIR RECIRCULATION COOLING AND FILTRATION SYSTEM

	Component	Malfunction	Comments and Consequences
A.	Containment Cooling Fan	Fails to start	Five provided. Evaluation based on three fans in operation and one containment spray pump operating during the injection phase.
B.	Nuclear Service Water Pumps	Fails to start	Three provided. Two required for operation.
C.	Automatically Operated Valves: (Open on automatic safeguards sequence)		
1)	Charcoal filter compartment butterfly valves	Fails to open	Five filters provided. Evaluation based on three filters in operation and one containment spray pump in operation during the injection phase.
2)	Nuclear service water discharge line isolation valve	Fails to open	Two provided. Operation of one required.

TABLE 2

SHARED FUNCTION EVALUATION

Component	Normal Operating Function	Normal Operating Arrangement	Accident Function	Accident Arrangement
Containment Cooling Fan Units (5)	Circulate and cool containment atmosphere	Up to five fan units in service	Circulate and cool containment atmosphere	Five fan units is service
Nuclear Service Water Pumps (3)	Supply river cooling water to fan units	Two pumps in service	Supply river cooling water to fan units	Two pumps in service
Charcoal Filter Units (5)	none	Isolated from normal fan discharge flow	Remove iodine from containment atmosphere	Lined up to receive fan discharge flow

4.0 INTRODUCTION

The analyses presented in this section demonstrate that the amount of radioactivity released to the environment in the event of a loss-of-coolant accident do not result in doses which exceed the limits specified in 10 CFR 100. In order to show more clearly the influence of the charcoal filter effectiveness on off-site inhalation doses, the dose resulting from iodine in organic form has been calculated separately as a function of filter efficiency. The doses at the site boundary and at the low population zone are presented in Figures 5.4-1 and 5.4-2. For the planned design, sixty filter cells will be installed, and two of the five installed filter units are assumed to be unavailable at the time of the accident. With a filter efficiency of 50% (exchange probability of 0.50) the two hour site boundary dose from organic iodine is 126 rem, and the 30 day dose at the low population zone is 136 rem.

Models For Dose Calculation

The time integrated form of the equation for inhalation dose is as follows:

$$D\,(x,T) = A_{131}(t=0)\cdot\frac{A_I}{A_{131}}(T)\cdot\alpha\cdot L(T)\cdot B(T)\cdot DCF_{131}\cdot\frac{X}{Q}\,(x,T)\cdot T\cdot\frac{1}{DRF(T)}$$

where the terms are defined as follows:

$D\,(x,T)$ = Dose received at position x during period T, rem

$A_{131}(t=0)$ = Initial activity of I_{131} in core at time zero, curies

$\frac{A_I}{A_{131}}(T)$ = Dose-equivalent factor to account for all isotopes of iodine, including decay during period T

α = fraction of core inventory assumed to be in organic form

$L(T)$ = containment leak rate during period T, ft^3/day per ft^3

$B(T)$ = breathing rate during period T, m^3/sec

DCF_{131} = dose conversion factor for I_{131}, rem per curie inhaled

$\frac{X}{Q}(x,T)$ = site dispersion factor at x for period T, Sec/m^3

T = time period over which dose is received, days

x = position at which the dose is evaluated, meters

DRF(T) = dose reduction factor for filters, for period T

The values of the terms defined above which were used in the calculations are given below, for the various periods which contribute to the total dose.

$A_{131}(t=0) = 7.94 \times 10^{7}$ curies

$$\frac{A_I}{A_{131}}(t) = \begin{cases} 1.84 & T = 0 - 2 \text{ hrs} \\ 1.47 & T = 2 \text{ hrs} - 24 \text{ hrs} \\ .34 & T = 24 \text{ hrs} - 31 \text{ days} \end{cases}$$

$\alpha = 0.025$

$$L(T) = \begin{cases} .1\% \text{ per day} & T = 0 - 24 \text{ hrs} \\ .045\% \text{ per day} & T = 24 \text{ hrs} - 30 \text{ days} \end{cases}$$

$$B(T) = \begin{cases} 3.47 \times 10^{-4} & T = 0\text{-}2\text{hrs} \\ 2.32 \times 10^{-4} & T = 2 \text{ hrs} - 30 \text{ days} \end{cases}$$

$DCF_{131} = 1.48 \times 10^{6}$ rem per curie inhaled

$\frac{\chi}{Q}(SB, 2hr) = 1.03 \times 10^{-3}$ $\quad T = 0 - 2$ hrs

$$\frac{\chi}{Q}(LPZ > T) = \begin{cases} 3.8 \times 10^{-4} & T = 0 - 2 \text{ hrs} \\ 1.9 \times 10^{-4} & T = 2 - 24 \text{ hrs} \\ 1.7 \times 10^{-5} & T = 1 - 30 \text{ days} \end{cases}$$

The dose reduction factor for the filters was evaluated for the various periods using the relationship.

$$\frac{1}{DRF(T)} = \frac{D}{1 + D} + \frac{1}{(1 + D)^2 \lambda (t_2 - t_1)} \left(e^{-\lambda (1 + D) t_1} - e^{-\lambda (1 + D) t_2}\right)$$

This expression was developed from the activity balance representing isotopic exchange in the filter, and the equation for production and removal of radioactive iodine from the containment atmosphere. The term "D" is the ratio of the total weight of iodine in the containment atmosphere at time zero (20 lbs) to the weight of iodine in the filters

The removal rate λ is given by the relationship:

$$\lambda = \frac{F\eta}{V_c}$$

where:

F = system flow rate, ft^3/hr
η = exchange probability
V_c = containment volume, ft^3

The total site boundary and low population zone inhalation doses may be obtained by adding the organic doses presented in Figures 5.4-1 and 5.4-2 to the doses resulting from elemental iodine.

Moisture Trapping by Carbon Beds

The accumulation of moisture loadings greater than that which would exist in equilibrium with a saturated steam-air atmosphere is minimized by the demisters and HEPA filters which treat the air entering the charcoal filter beds. The demisters will remove 99% of moisture droplets above 1 μ diameter. Of those droplets which penetrate the demister, a large percentage would be removed by the HEPA filter, which has removal capability extending into the sub-micron range.

To evaluate the effectiveness of this protection, a source of entrained droplets was postulated consisting of the average concentration of spray droplets smaller than 540 μ in the containment atmosphere. (Larger droplets were calculated to fall out in the plenum ahead of the filters.) Of the smaller droplets, 99% were assumed to be removed by the combination of demister and HEPA filter effectiveness. All of the remaining water was assumed to accumulate on the charcoal bed. The resultant moisture loading represented an increase of less than 2% of the charcoal weight per day.

If the equilibrium moisture loading by adsorption is assumed to be 60% (dry basis), twenty days of continuous spray and filter operation would not raise the total loading above 100%, a level at which pore flooding could occur. Even at this point, some exchange effectiveness remains. Moreover, it is not expected that spray operation would extend beyond the first day after the accident, hence the entrainment model is highly conservative.

2-HR SITE BOUNDARY DOSE FROM 2.5% CORE I as CH_3I

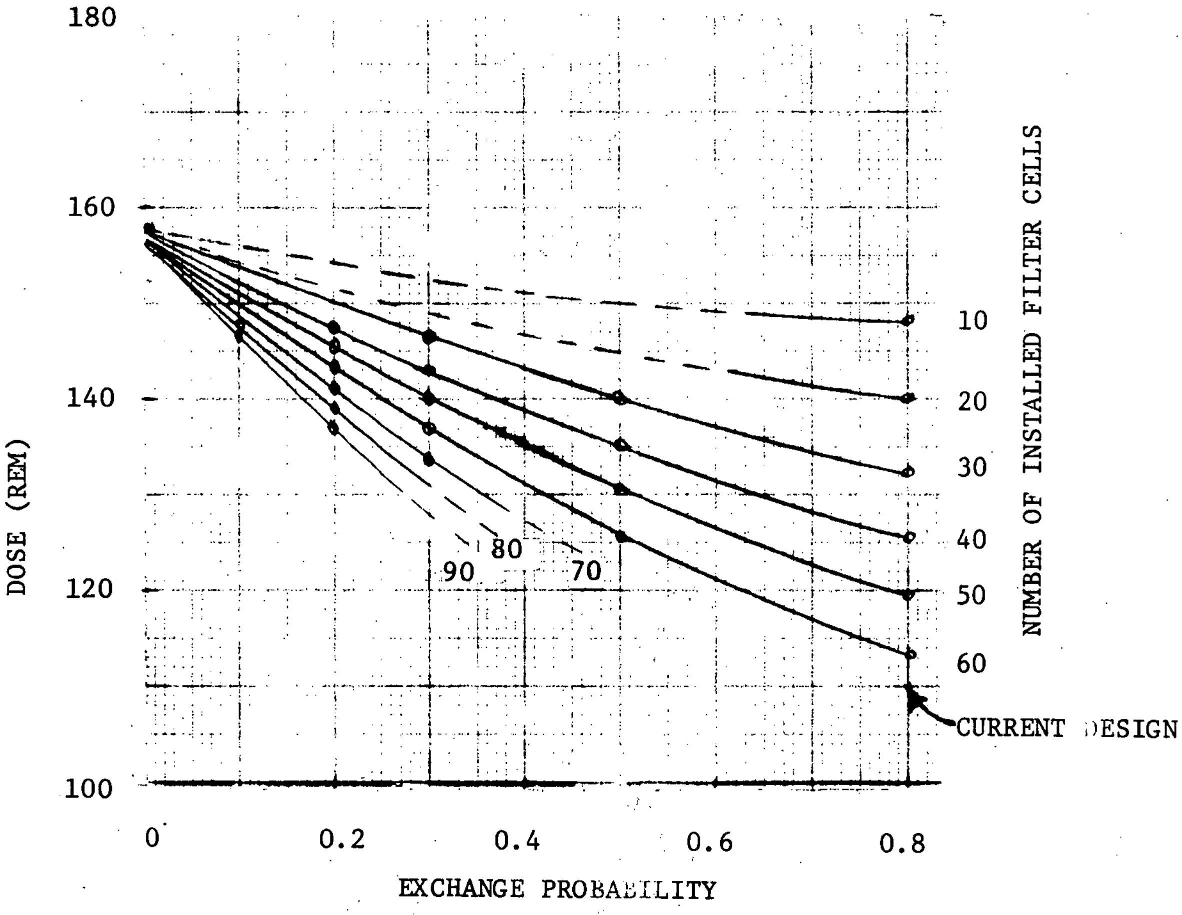


FIGURE 5.4-1

Supplement 7

30 DAY LPZ DOSE FROM 2.5% CORE
I AS CH_3I

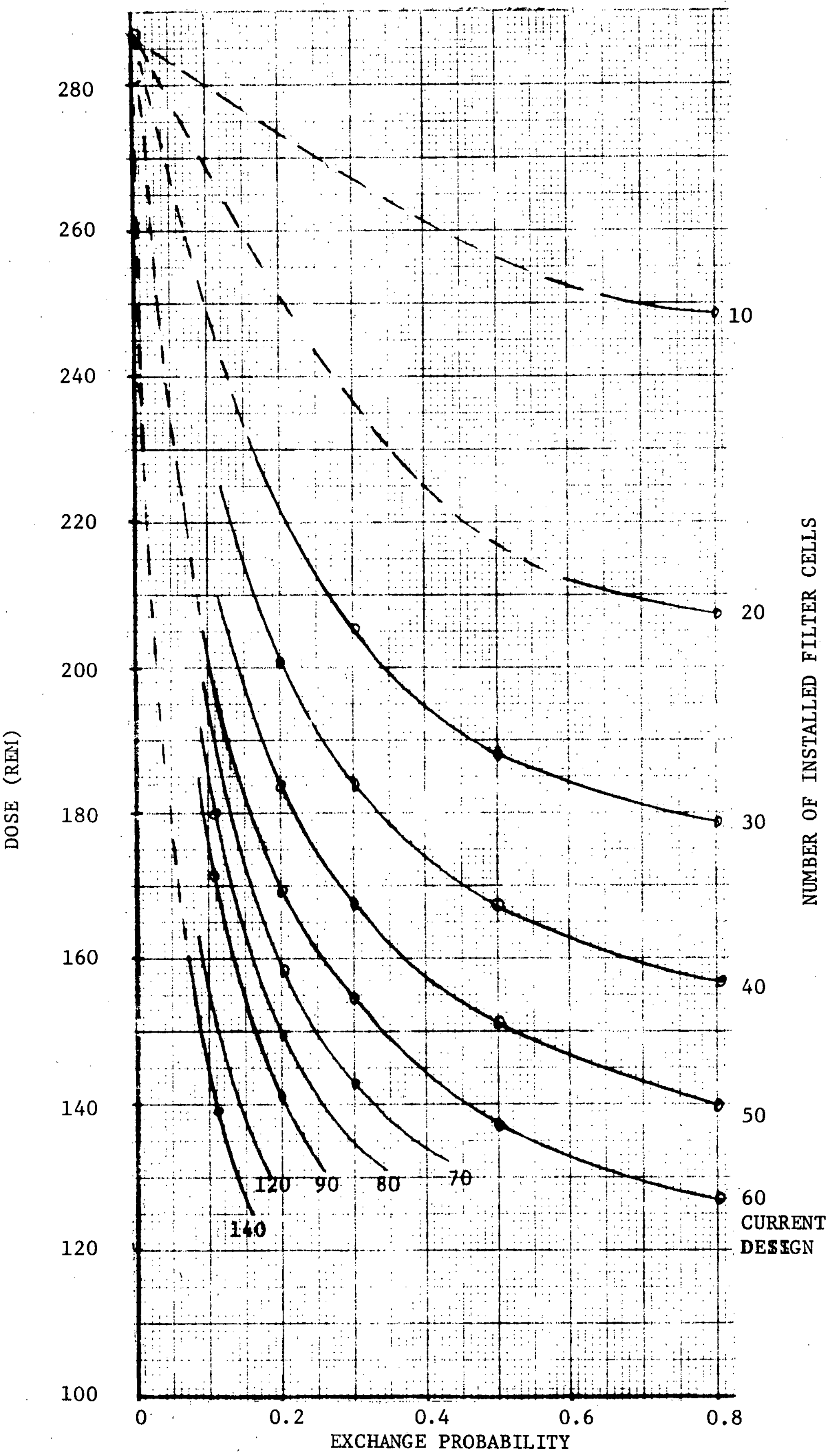


FIGURE 5.4-2

QUESTION 6 (a)

As discussed at our meeting on October 25, 1968, the following information is required in the areas of electrical power, instrumentation and control, cable routing, and radiation monitoring:

> Please state your criteria, and design intent, with respect to the physical separation of redundant power lines (sources of offsite power) connecting the station with the Buchanan substation.

ANSWER

The answer to this question is covered in Item 15 of Supplement 5 as revised by Supplement 6.

QUESTION 6 (b)

As discussed at our meeting on October 25, 1968, the following information is required in the areas of electrical power, instrumentation and control, cable routing, and radiation monitoring:

> With reference to Supplement 5 to the PSAR, we understand that the 6.9 KV connection to auxiliary bus sections 5 & 6 automatically occurs upon loss of the 138 KV supply. Will the connection occur if the voltage loss is downstream of the 138 KV feeders? For example, will failure of the station auxiliary transformer result in the automatic connection?

ANSWER

The answer to this question is found in Item 15 of Supplement 5 as revised in Supplement 6 to the PSAR.

QUESTION 6 (c)

As discussed at our meeting on October 25, 1968, the following information is required in the areas of electrical power, instrumentation and control, cable routing, and radiation monitoring:

> Please provide a failure mode analysis to show that the complexity on your proposed on-site emergency power system in no way leads to circuitry designs which violate the single failure criterion.

ANSWER

The answer to this question is found in Supplement 1 to the PSAR, Item 17 (F-2.0) as revised by Supplement 6 to the PSAR.

QUESTION 6 (d)

As discussed at our meeting on October 25, 1968, the following information is required in the areas of electrical power, instrumentation and control, cable routing, and radiation monitoring:

> State and discuss your criterion with respect to minimum storage requirements of emergency fuel supplies.

ANSWER

The answer to this question is found in Supplement 1 to the PSAR, Item 17 (F-1.0) as revised by Supplement 6 to the PSAR.

QUESTION 6 (e)

As discussed at our meeting on October 25, 1968, the following information is required in the areas of electrical power, instrumentation and control, cable routing, and radiation monitoring:

> State and discuss your criterion with respect to load margins for the emergency power system. Please include system sensitivity to unexpected load increases which diminish the design margins.

ANSWER

The offsite emergency power supply feeds power to the 480 volt engineered safeguards systems through the four station service transformers each of which is rated at 2666 KVA continuous. Under safeguards injection phase loading, which is automatic, the maximum load on each unit will not exceed the transformer continuous rating. The transformers have short time overload capability in accordance with ASA Appendix C 57.95 "Guide for Loading---." The onsite emergency power units (Diesel Generators) are each rated at 2250 KW - 1/2 hour. Under safeguards injection phase loading, which is automatically sequenced and applied, the maximum load on each unit will not exceed this rating. Under the three diesel on case all safeguards loads are sequenced on and overloading through unexpected load application cannot occur. All unnecessary loads are tripped and locked off through redundant interlocks on occurrence of a safety injection signal.

Further information on diesel generator loading is found in Supplement 1, Item 17 (F-1.0). Table 1 of this item should be corrected to give the total kw loadings of 3159 kw for the injection phase and 3164 kw for the recirculation phase.

QUESTION 6 (f)

As discussed at our meeting on October 25, 1968, the following information is required in the areas of electrical power, instrumentation and control, cable routing, and radiation monitoring.

> Discuss the protection provided for the diesel generators which prevents a failure in one diesel generator (e.g., fuel line failure and ensuing fire, failure of rotating machinery, etc.) from disabling the other units.

ANSWER

The building housing the diesel generators will have fire barriers between each diesel with the associated switchgear and cabling local to each diesel such that a fire in one compartment cannot affect the operation of the other diesels. Missiles generated by the diesels is considered incredible based upon the manufacturer's operating experience.

Field case history of the Alco model 251 engine discloses a complete absence of damage to the engine environs as a result of engine component failure. Engine failures, usually the result of extreme operating conditions, can be classed as follows:

a. A valve sticks open and is struck by the piston. The damaged valve and possibly part of the piston enters the exhaust manifold, damage the turbo charger, and pass harmlessly up the stack. No missiles fly around in the engine room.

b. A piston seizes and causes bending and eventual fracture of the connecting rod. All damaged parts remain inside the engine block.

c. A turbo charger turbine wheel fouls the casing as a result of overspeed or overheat. The robust double walled casing contains all parts.

d. An overspeed trip, which shuts off fuel at each individual fuel injection pump, stops the engine at 10% overspeed. No cast iron is used in the engine block and base so that even if the overspeed trip failed, the engine structure, which is brittle by nature, would contain any fracture parts. Isolation cases of crank shaft fractures have resulted in no flying missiles.

e. Cylinder heads are secured to the block by high tensile studs. No cap gaskets are used between the head and cylinder liners. This pre-stressed design, with no possibility of slackness developing, has resulted in an assembly which has had no incidents of heads flying off, even when failed pistons have pounded the heads. Cases also are on record of improperly timed engines resulting in excessively high firing pressures, over 2,000 psi and the heads have always remained intact.

Missiles flying from the engine are not a problem with the Alco engine. Alco does not have any evidence of blades coming through the turbo casing. Valves from the engine have broken and been exhausted through the turbo and caused damage to turbo, but are contained within the casing. There is no evidence of connecting rods flying from the engine.

The generator would have to be in an overspeed condition beyond what is normally possible with a diesel engine, in order to generate any flying parts. The construction of the stator windings and stator barrel frame would have to be penetrated by a rotor part in order to escape. The rugged construction of each complements their ability to contain flying objects.

Since the engine has an overspeed trip and would not operate much beyond this speed because the valves would hang up, it is felt that the generator would never reach any critical speeds.

QUESTION 6 (g)

As discussed at our meeting on October 25, 1968, the following information is required in the areas of electrical power, instrumentation and control, cable routing, and radiation monitoring:

> Please discuss, and justify, your criterion relating to the routing of redundant instrumentation, control and power cables associated with protection and safety feature equipment. Your response should include the following considerations.
>
> (1) Minimum physical separation (horizontal and vertical) between instrumentation, control, and power cables.
>
> (2) Minimum physical separation between redundant cables.
>
> (3) Cable array loading.
>
> (4) Fire barriers at cable trays.
>
> (5) Fusing and/or breaker protection for 3-phase circuits.
>
> (6) Administrative responsibility for, and control over, the foregoing during design and installation.

ANSWER

The answer to Items (1) through (4) is found in Supplement 1 to the PSAR, Item 17 (F-1.0) as revised by Supplement 6 to the PSAR. The administrative responsibility for the design and installation is described in the quality control program found in Supplement 1, Item 5 and Supplement 5, Item 4.

All power circuits at 6.9 kv are protected by 3 phase power circuit breakers. In the 485 volt system all loads connected to the 485 volt busses are also protected by 3 phase circuit breakers. This includes all feeds to motor control centers. All large motors above 100 HP are supplied through circuit breakers. The pressurizer heaters are also supplied through 3 phase circuit breakers. Individual small motors supplied from motor control centers are protected by a combination of fused disconnect switches and motor starters equipped with thermal overloads. The fuses are sized for short circuit protection and will operate to disconnect a faulted phase. The overload devices in the motor starter will open all three phases on a motor overload but are not designed to interrupt short circuits in the cable system. In the event of a fault on one phase in the cable tray system, the fuse in that phase will blow. If the faulted phase is one of the two phases to which the control transformer is connected, the low control voltage will open the motor starter and disconnect all three phases. If the faulted phase is not connected to the control transformer, the motor may continue to operate single phase. Under these conditions, the motor current will rise and the thermal overload will operate to disconnect all three phases if the motor was operating near full load. The use of the fused disconnects provides the most reliable interrupting device in the sizes considered. These devices also serve an important safety function in providing an open visible break in the circuit during maintenance operations. They have been used for many years with excellent results.

QUESTION 6 (h)

As discussed at our meeting on October 25, 1968, the following information is required in the areas of electrical power, instrumentation and control, cable routing, and radiation monitoring:

> Please discuss, and justify, your criterion relating to the physical separation of redundant instrumentation.

ANSWER

The answer to this question is found in Supplement 1 to the PSAR, Item 17 (F-1.0) as revised by the Supplement 6 to the PSAR.

QUESTION 6(i)

As discussed at our meeting on October 25, 1968, the following information is required in the areas of electrical power, instrumentation and control, cable routing, and radiation monitoring:

> Please discuss the status of the environmental tests being performed on vital components and wiring located within containment.

ANSWER

A series of combined pressure, temperature, and spray chemistry environmental tests have been performed on typical vital electric motors located within the containment. Approximately 80 hours of testing under load conditions have been completed on a fan cooler motor at a pressure and temperature of 78 psig and 290°F respectively. Chemical spray was injected during approximately 20% of the tests. The motor performed satisfactorily during the tests. The motor has been partially disassembled and visually inspected. The motor windings were found to be in excellent condition.

A production line valve operator motor has been irradiated to a level of approximately 2×10^8 rads and is presently undergoing testing; concurrently, an identical unirradiated motor is also being tested. Containment pressure, temperature, and humidity tests are being conducted on valve motor operators.

Sections of both power and instrument cables for safeguards related equipment are on order and will be tested at the containment post accident environment conditions.

Test specifications are being prepared for testing safety related instrumentation which must remain functional in the post accident containment environment.

QUESTION 6 (j)

As discussed at our meeting on October 25, 1968, the following information is required in the areas of electrical power, instrumentation and control, cable routing, and radiation monitoring:

> We understand that the rod withdrawal inhibit circuits which prevent withdrawal in the event of a dropped rod (or rods) will be designed in accordance with IEEE 279. Please confirm.

ANSWER

The answer to this question is found in Supplement 1 to the PSAR, Item 2 (1-11) as revised by Supplement 6 to the PSAR.

QUESTION 6(k)

As discussed at our meeting on October 25, 1968, the following information is required in the areas of electrical power, instrumentation and control, cable routing, and radiation monitoring:

> Please state, and justify, your criterion relating to redundancy of radiation monitoring systems which act to prevent inadvertent gaseous and liquid releases. Also, please identify those which provide automatic isolation action, and those which do not, and justify your choice in each case.

ANSWER

Containment

The radiation monitoring equipment for the containment has been designed to operate in a manner which prevents inadvertent release of activity from the containment. Inadvertent release from the containment cannot occur because,

1. The containment is not purged during power operation
2. The containment atmosphere is continuously monitored for both radiogas and air particulate activity
3. Both the radiogas and air particulate detectors are provided with a check source
4. Prior to initiating containment purge the containment air activity is checked
5. During containment purging operations, the containment is automatically isolated by high level alarms in either the radiogas or air particle detectors.

Waste Disposal System

The procedure for discharging liquid wastes is as follows;

1. A batch of waste is collected in one waste condensate tank

2. The tank is isolated

3. The tank contents are recirculated to mix the liquid

4. A sample is taken for radiochemical analysis

5. If analysis indicates that release can be made within permissible limits, the quantity of activity to be released is recorded on the basis of the liquid volume in the tank and its activity concentration. If release cannot be made within permissible limits, the waste is returned to the waste holdup tank

6. To release the liquid, the last stop valve in the discharge line (which is normally locked shut) must be unlocked and opened; a second valve, which trips shut automatically on high radiation signal from the monitor, must be opened manually; a waste condensate pump must be started manually and the normal 20 gpm flow rate established on the flow indicator provided; and finally the recirculation valve must be closed. Liquid is now being pumped overboard.

As the operating procedure indicates, the release of liquid waste is under administrative control. The monitor is provided to maintain surveillance over the release.

The monitor is provided with the following features:

1. A calibration source is provided to permit the operator to check the monitor before discharge by pressing a button in the control room to activate the circuitry

2. If the monitor falls off scale at any time, an indicator visible to the operator in the control room will light

3. If the power supply to the monitor fails, a high radiation alarm will annunciate. The trip valve will also close.

4. The radiation trip valve is fail closed, normally closed.

It is concluded that the administrative controls imposed on the operator combined with the safety features built into the equipment provide a high degree of assurance against accidental release of waste liquids. Since a second monitor could do very little to increase that assurance, we conclude that a second monitor is not needed.

The procedure for discharging gaseous wastes is as follows:

1. Four large waste gas hold-up tanks are provided; discharge is limited to only one tank at a time. The gas is discharged to atmosphere by discharge with the plant ventilation air.

2. Before any discharge is permitted, a sample is taken from the appropriate tank to determine the activity concentration and total active inventory.

3. If analysis indicates that release can be made within permissible limits, the quantity of activity to be released is recorded on the basis of the tank pressure and volume and its activity concentration.

4. To release the gas, the appropriate manual stop valve is opened, the first air operated valve is opened and the second valve, i.e., the gas release valve, is opened in small increments. To assist the operator in setting the discharge valve and thus the release rate, a radiation monitor is provided in the plant ventilation discharge duct and the activity level is displayed on the control panel. On high radiation level alarm the gas release valve is automatically closed.

   As the operating procedure indicates, the release of gaseous waste is under administrative control. The monitor is provided to maintain surveillance over the release.

The monitor is provided with the following features:

1. A calibration source is provided to permit the operator to check the monitor before discharge by pressing a button in the control room to activate the circuitry
2. If the monitor fails off scale at any time, an indicator visible to the operator in the control room will light
3. If the power supply to the monitor fails, a high radiation alarm will annunciate. The gas release valve will close automatically.
4. The radiation trip valve is fail closed, normally closed.

It is concluded that the administrative controls imposed on the operator combined with the safety features built into the equipment provide a high degree of assurance against accidental release of waste liquids. Since a second monitor could do very little to increase that assurance, we conclude that a second monitor is not needed.

Steam and Auxiliary System

One radiation element is in the common discharge line from the steam jet air ejectors. The effluent from the air ejectors is diverted to the containment on high radiation. This signal also closes the steam supply valve to the priming ejectors. Automatic action was selected to minimize release of radioactive gases while maintaining the condenser for steam dump.

Continuous sampling is done of the steam generators. These samples are passed by one common radiation element. High radiation will automatically isolate both the blowdown and sampling systems. Automatic isolation of these systems will not affect the immediate operation of the plant.

The radiation elements in the air ejector vent and blowdown systems are redundant one to the other.

Samples are taken from the discharges of the fan coolers and passed by two radiation elements in series. These elements activate an alarm in the control room. No automatic action is taken; manual analyses are required before isolating the leak. Automatic operation will affect the operation of the fan coolers which is undesirable following the accident. Redundancy is provided by two elements in series.

QUESTION 6(1)

As discussed at our meeting on October 25, 1968, the following information is required in the areas of electrical power, instrumentation and control, cable routing, and radiation monitoring:

> We are concerned that a trip of the unit generator may have an adverse effect on the stability of the external grid if the reserve generating capacity of the grid were diminished. Please provide your evaluation of this occurrence.

ANSWER

The basic criteria for design and operation of the Consolidated Edison power system requires that the overall system be designed and operated in such a manner that the stability of the interconnected system shall be maintained for any loss of any generator. This criterion must be met for any system condition as for example when major transmission facilities are out of service. Digital computer studies are conducted to determine how the overall system must be operated for any system condition to insure that this criterion as well as a number of others will be met. This particular incident has been simulated with the power system stability program for the G E 625 computer using full representation of the generators governor systems and excitation systems of all machines on the system. It was found that loss of the unit generator would have no adverse effect on the interconnected systems.

The stability of the interconnected systems would not be adversely affected by any reduction in reserve generating capacity. System stability is a function of the configuration of the system at a given time, including amount and location of loads, size and location of generators, and system impedances, and also a function of the characteristics including the governor and excitation system parameters of the individual generating units running at the time of the disturbance. Reserve generating capacity is not a factor. System instability occurs when one group of machines slips a pole with respect to another group of machines, that is when they become separated by 360 electrical degrees. As one group begins to go out of phase with respect to the other, voltages at various points in the system will approach zero. These zero voltages will be detected by protective devices on the system and interpreted as faults. Consequently lines will open to effectively isolate one group of machines from the other. Numerous tests have shown that this phenomenon will usually occur within 5 seconds or longer before the reserve generating capacity, no matter how great, can have any noticeable effect. Thus a shortage in available reserve will not have any appreciable effect on system stability. Since the system is designed and operated in such a manner that the stability of the interconnected systems will be maintained for the loss of any generator, and since the stability of the interconnection is not a function of the reserve generating capacity available, a trip of the unit generator will not have an adverse effect on the stability of the external grid, even if the reserve generating capacity of the grid were diminished.

QUESTION 6(m)

As discussed at our meeting on October 25, 1968, the following information is required in the areas of electrical power, instrumentation and control, cable routing, and radiation monitoring:

> State the length of time the batteries can supply essential loads without assistance from the battery chargers.

ANSWER

The batteries can supply the essential loads for 2 hours without assistance from the battery chargers.

QUESTION 6(n)

As discussed at our meeting on October 25, 1968, the following information is required in the areas of electrical power, instrumentation and control, cable routing, and radiation monitoring:

> Discuss the protection provided to the station batteries which prevents disablement of these batteries by a single failure or a single external event.

ANSWER

The D. C. System consist of two batteries supplying two separate independent buses. The batteries are protected by fuses near each battery. The two D. C. buses normally are electrically separated with a non-automatic breaker tie for flexibility purposes. Essential D. C. supply circuits are redundant with feeds from each bus and all D. C. circuits are separately protected by circuit breakers at their respective D. C. bus. Each D. C. bus has its own battery charger.