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OAK RIDGE NATIONAL LABORATORY

UNION CARBIDE

Criteria for Controlled Atmosphere Chambers

J. N. Robinson

OPERATED BY
UNION CARBIDE CORPORATION
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DEPARTMENT OF ENERGY

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PREFACE

This report represents the culmination of some ten years' effort by a number of people. The need for formal criteria was recognized by T. A. Arehart and R. G. Affel in 1970, and the evolution of these consolidated criteria has proceeded slowly.

Many people have contributed, some of whom are:

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CRITERIA FOR CONTROLLED ATMOSPHERE CHAMBERS

I. INTRODUCTION

This document presents the criteria for design, construction, and operation of controlled atmosphere chambers intended for service at the Oak Ridge National Laboratory. These criteria are considered appropriate to ensure both safe and reliable operation. For reference, the ORNL procedure that implements these criteria (ORNL Safety Manual Number 2.1) is presented in Appendix "A."

The term "controlled atmosphere chambers" is generic, and is intended to include all equipment items which provide a sealed containment boundary between the operator and the operation and which are subject to an internal pressure between full vacuum and a positive pressure of 15 psig. Controlled atmosphere chambers are usually provided with viewing windows so the operator can observe and control the operation, are equipped with gauntlet gloves, and operate at a slight pressure differential (0.2-2 in. w.g.). It is not intended that these criteria apply to massively shielded enclosures (hot cells) or unsealed enclosures where air flow is relied on to control contamination (hoods, open face gloveboxes).

These criteria include controlled atmosphere chambers and the operating and control system of which they are a part. Although it is not intended that exhaust ducting, filter systems, or systems pressurized at greater than 15 psig be covered by these criteria, there is no intentional conflict with the requirements for those services.

Requirements and recommendations are both included here. Compliance with requirements is mandatory and is indicated by the use of "shall" or "must." Recommendations are provided for guidance, are not mandatory, and are indicated by the use of "should" or "may."

II. CLASSIFICATION OF CHAMBERS

For descriptive purposes, controlled atmosphere chambers are divided into four service classes. These classes are applied to the operation and to the chamber, it being intended that the chamber be of a class equal to or better than the operation.

Class A service is that in which violation of the containment barrier to the extent that contained materials can escape the chamber is totally unacceptable. There are normally no applications for which this level of integrity is required, but it is provided for those instances in which the responsible individual, considering the nature of his operation, elects to invoke these more stringent criteria.

Class B service is that in which a violation of the containment barrier could result in a major safety hazard. The following must at least be classified as Class B: (1) a chamber containing any quantity of highly reactive, pyrophoric, or explosive materials and type B Laboratory* levels of radiotoxic materials, (2) a chamber containing a heat source equivalent to 1000 watts or greater, or (3) a chamber containing type A Laboratory* levels or radiotoxic materials or equivalent levels of biologically hazardous or toxic materials.

Class C service is that in which a violation of the containment barrier could result in a significant safety hazard. The following must at least be classified as Class C: (1) a chamber containing type B Laboratory* levels of radiotoxic materials, or equivalent levels of biologically hazardous or toxic materials, or (2) a chamber containing significant quantities of highly reactive, pyrophoric, or explosive materials.

Class D service is that in which extensive violation of the containment barrier would not result in a significant safety hazard. Examples of Class D service are the inert gas blanketing of a welding or of a chemical operation where the purpose of the blanket is to maintain purity or the use of a filtered flow-through box to maintain cleanliness.

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*Procedures and Practices for Radiation Protection — ORNL Health Physics Manual, Appendix A-7 (See Appendix "B").

III. MATERIALS OF CONSTRUCTION

Any material that is compatible with the operation to be performed may be used for the construction of chambers. For Class A, Class B, or Class C chambers, metal — austenitic stainless steel preferably — is strongly recommended. To the extent possible, metallic materials of construction shall be those for which allowable stresses are given in Sect. VIII, Division 1 of the ASME Boiler and Pressure Vessel Code. Viewing windows may be of laminated or unlaminated glass or of polycarbonate plastic (Lexan). Windows of Class A and Class B chambers must be of laminated glass (with the specific approval of the Office of Operational Safety, windows of Class B chambers having a design pressure less than or equal to 6 in. w.g. and dimensions of less than 42 in. × 30 in. may be of 3/8 in. thick laminated polycarbonate plastic).

IV. DESIGN CRITERIA

For each chamber, design conditions (maximum service pressure and coincident temperature) shall be specified. Each box shall be marked with those conditions and the service class for which it is acceptable.

> Many terms are in use: design pressure, operating pressure, normal operating pressure, maximum pressure, maximum operating pressure, extreme pressure, etc. A single term, "design pressure," is used here and it is intended that under no circumstances may a chamber be exposed in service to a greater pressure differential.

A chamber intended for service at a pressure differential of 6 in. w.g. or less shall be designed for a pressure differential of 6 in. w.g. A chamber intended for service at a pressure differential greater than 6 in. w.g. shall be designed for a pressure differential of 15 psig.

> Controlled atmosphere chamber operations usually require either a slight pressure differential or the ability to go to full vacuum (for purging the atmosphere). Recognizing this, the above requirement eliminates the danger of an uncontrolled pump exhausting a chamber beyond its capability and causing a failure.

V. DESIGN

The structural components of each chamber shall be designed to conform to the intent of Sect. VIII, Division 1 of the ASME Boiler and Pressure Vessel Code. Using elementary stress formulas, such as those of Sect. VIII or of Roark,* stresses in the chamber shall not exceed those of the stress tables in Sect. VIII. (The lesser of 0.25 times the ultimate tensile strength or 0.625 times the yield strength of the material).

Viewing windows shall be designed in accordance with Appendix "C" of this criteria. The minimum factor of safety for windows shall be (values are for new windows/existing windows):

	Minimum factor of safety[a]			
	Class D	Class C	Class B	Class A
Pressure ≤6 in. w.g.				
Annealed glass	8/4	NA	NA	NA
Tempered glass	8/4	NA	NA	NA
Laminated annealed glass	4/2	8/4	10/6	15
Laminated tempered glass	4/2	8/4	10/6	15
Plastic	4/2	10/6	NA	NA
Pressure > 6 in. w.g.				
Annealed glass	10[b]/6[b]	NA	NA	NA
Tempered glass	10[b]/6[b]	NA	NA	NA
Laminated annealed glass	6/4	10/6	10/6	15
Laminated tempered glass	6/4	10/6	10/6	15
Plastic	6/4	10/6	NA	NA

[a] The factor of safety is the ratio of the calculated pressure at which the material will crack (based on long-term loading for glass) to the specified design pressure.

[b] Must be provided with a missile screen (wire mesh or plastic sheet) capable of containing broken glass or other missiles while relieving pressure differential.

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*Roark, Raymond J., *Formulas for Stress and Strain* (4th ed., New York; McGraw Hill, 1965).

1. General considerations for chamber design include (a) operating convenience, (b) adequate lighting, (c) adequate vision, (d) convenient working height, (e) fire and corrosion resistance, (f) ease of decontamination, (g) eventual disposal, (h) control of atmosphere, and (i) material entry and exit.

2. Glove ports shall not exceed 8 in. nominal size and shall not be installed in any glass window.

3. For Class A, Class B, and Class C chambers, gloves shall be secured to glove ports with two clamping devices, at least one of which shall be a mechanical clamp (Reliance cannot be placed solely on "O" rings).

4. Bag-out ports shall be installed in metal or other equally rigid structure.

5. The need for closures (covers or bungs) for glove and bag ports shall be given consideration.

    Bungs are provided to improve the integrity of an opening during the time it is not in use. Covers serve this purpose and also seal off the opening so the chamber can be subjected to a greater pressure differential (as for purging the atmosphere). The presence of bungs or covers can be helpful in controlling the consequences of a torn glove or a leaky connection. In each case, why a bung or cover is provided should be explicitly recognized and the design should implement that purpose — for instance, a bung might be intended to keep a glove from entering a chamber in which case it does not require a seal, or it might be intended to serve as a containment barrier, in which case it does require a seal.

6. The need for high temperature detectors, fire control systems, combustible gas sensors/alarms, gas or vapor analyzers, and explosion-proof equipment shall be considered.

7. Chambers provided with water service shall be equipped with controls to prevent flooding in the event of a leak, or to activate an alarm if a leak occurs.

8. Electrical safeguards shall be provided for equipment and personnel. The use of grounding, ground fault interrupters, overload protection, and independent fusing should be considered.

9. Where possible, light sources shall be installed outside of the chamber.

10. Internal corners should be coved, to facilitate cleaning.

11. Internal weld surfaces shall be ground flush and smooth to facilitate cleaning.

12. Exhaust air connections shall be provided with debris screens to prevent trash from entering exhaust systems and burning material from reaching filters. Consideration shall be given to the need to protect exhaust filters from hot gases in the event of a fire.

13. Consider provision of a foot- or knee- operated safety switch (with manual reset) to turn off electrically powered machinery within the chamber in addition to other controls.

14. An easily observed differential pressure indicator shall be provided for each chamber.

15. If used for Class A service chambers, "H" gaskets shall be sealed to the chamber and to the window with a mastic.

16. Windows shall be of the smallest size that will satisfy functional requirements.

VI. CONTROLLED ATMOSPHERE CHAMBER SYSTEMS

A controlled atmosphere chamber system consists of the chamber itself and any other equipment, piping, or controls (permanent or temporary) that can affect its operating conditions, including (1) pressure and flow controls, (2) filters, (3) fire control, (4) associated gloves, bags, port closures, (5) pressure relief devices, (6) exhaust fans, (7), exhaust ducts (to a pressure/flow control device), (8) alarms, indicators, and monitors, and (9) heat sources.

Each system shall be designed and reviewed as a whole, to ensure that it is capable of controlling operating conditions within the specified design conditions of the associated chambers. Design shall be such that this control is maintained in the event of power failure or the malfunction of any device in the system.

1. When a Class A, Class B, or Class C chamber is connected to an exhaust system,
   - (a) high efficiency (HEPA) filters shall be provided at the air inlet to and discharge from the chamber. To be effective these filters must (1) maintain the specified high filtration efficiency and (2) not become plugged to the extent that free flow cannot be maintained. Usual installation of inlet filters does not permit testing to verify that they retain acceptable flow characteristics. Each design shall include provision for (1) periodic testing of inlet filters or (2) periodic replacement of inlet filters. Consideration should be given to the need for a flow indicator that can continually monitor the volume of air inflow.
   - (b) Two stages of DOP testable HEPA filters shall be provided in series before exhaust is released to atmosphere. Where HEPA filters are not adequate, as for radioactive gases, scrubbers, absorbers, or adsorbers shall also be used.
   - (c) Piping, pressure differential, and control shall be such that air velocity at the largest opening, with glove or bag removed, is at least 100 ft/min. Where demonstration of this, by actual test, could spread contamination, calculations may be used to demonstrate compliance.

2. Systems shall have appropriate pressure and/or vacuum regulators and relief devices to ensure that under no circumstances is the design pressure exceeded. It must be presumed that any device will malfunction in the most detrimental manner. Relief devices are not required if the chamber <u>cannot</u> be connected to a source of pressure or vacuum exceeding ±5 in. w.g. Consideration shall be given to the possibility of concurrent failure of normal exhaust flow controls and of those for gas service to the chamber.

3. If bubblers are used for pressure or vacuum relief, they shall be of transparent construction to permit a visual check for the presence of the correct quantity of sealing fluid.

4. Vacuum or pressure relief devices of Class A, Class B, or Class C chambers shall be provided with HEPA filters. These filters shall not be shared with any flowing system.

   The filters are required so that contamination released in connection with a pressure surge (1) will not be released to the room or (2) will not contaminate the exhaust ducting. These filters cannot also serve a flowing system because, if they did, they might become plugged under normal conditions and not be effective when called upon to function in an emergency.

5. System design shall recognize any need for a high flow rate of gas to provide dilution of flammable vapors or dissipation of heat loads. Operating procedures to ensure that the flow rate is adequately controlled shall be established.

6. Consideration shall be given to the need for remote alarm systems to signal malfunctions of the pressure control system when the system is unattended. To be effective, alarms must signal in a controlled area which is continuously monitored.

7. Consideration shall be given to the need for electrical grounding of metal chambers. Where needed, grounding shall be provided.

8. The review of controlled atmosphere chamber installations shall be based on the assumption that there <u>will</u> be a fire, either inside or near the chamber. Protective systems shall both minimize the likelihood of a fire and minimize the consequences of a fire.

9. Consideration shall be given to sources of liquid or compressed gases that are connected to the chamber. Such sources shall be provided with flow-limiting orifices or fail-shut regulators to protect the chamber from over pressurization.

VII. BEFORE OPERATION

1. Operations to be performed in the chamber shall be reviewed to ensure that they impose no conditions on the chamber which exceed the design conditions. Particular attention should be paid to the possible use of materials which might ignite or mechanical clamps or presses which might slip and release a missile.

2. The pressure control system shall be demonstrated to be effective by actual demonstration, by simulating malfunctions, in the most detrimental manner, of all pressure control elements, and by interrupting the power supply without the pressure exceeding the design pressure.

3. Glass containers that are to be operated as vacuum or pressure equipment (bell jars, glass process equipment) shall be visually inspected before use and periodically during use. The presence of defects or damage from handling which might prevent safe operation shall be cause for replacement of the container.

4. Glass containers having volume greater than five liters which are operated as vacuum or pressure equipment shall be provided with perforated metal guards or with plastic missile shields.

VIII. DURING OPERATION

1. Highly flammable solvents* may not be used in Class A or Class B controlled atmosphere chambers. When flammable solvents must be used:
   (a) The quantity of solvent used shall be restricted to the minimum necessary.
   (b) Provision shall be made for diluting vapors or inert gas blanketing to the maximum extent possible.
   (c) As quickly as possible after use, solvents and any saturated material shall be removed from the chamber.

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*Acetone, alcohol, benzene, ether, gasoline, naptha, toluene, etc.

REFERENCES

This document incorporates the following:

1. ORNL Safety Manual, Number 2.1, issued July 27, 1971 (under revision).
2. ORNL Safety Manual, Appendix A-3, issued November 11, 1974 (obsolete and removed from Manual).

This document accommodates the recommendations of:

1. Lawrence Livermore Laboratory, VI. Gloved Boxes, August 15, 1972.
2. ASTM Standard C852 (draft), July 19, 1976.

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20. *Serious Accidents*, "Small Metallic Plutonium Fire Leads to Major Property Damage Loss," Issue No. 130, USAEC, November 27, 1957.

21. *Serious Accidents*, "Drybox Explosion Disperses Plutonium Contamination," Issue No. 148, USAEC, October 8, 1959.

22. *Serious Accidents*, "Plastic Windows and a $125,000 Sprinkler Head," Issue No. 152, USAEC, October 29, 1959.

23. *Serious Accidents*, "Glove Box Explosion," Issue No. 180, USAEC, November 20, 1961.

24. *Serious Accidents*, "Filter Box Fire," Issue No. 217, USAEC, February 7, 1964.

25. *Serious Accidents*, "Explosion Within Glovebox Disperses Contamination," Issue No. 242, USAEC, January 11, 1965.

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31. *Serious Accidents*, "Fire Damages Hot Cell Window," Issue No. 275, USAEC, November 4, 1966.

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APPENDIX A

CONTROLLED ATMOSPHERE CHAMBERS

A. Policy

It is the policy of the Oak Ridge National Laboratory that controlled atmosphere chambers be recognized as potentially hazardous and that appropriate precautionary procedures be followed relative to their design, construction, and use.

B. Definitions

1. Controlled Atmosphere Chambers: The term "controlled atmosphere chambers" is generic, and is intended to include all equipment items which provide a sealed containment boundary between the operator and the operation and which are subject to an internal pressure between full vacuum and a positive pressure of 15 psig. Controlled atmosphere chambers are usually provided with viewing windows so the operator can observe and control the operation, are equipped with gauntlet gloves, and operate at a slight pressure differential (0.2-2 in. w.g.). It is not intended that these criteria apply to massively shielded enclosures (hot cells) or unsealed enclosures where air flow is relied on to control contamination (hoods, open face gloveboxes).

C. Responsibilities

The Office of Operational Safety is responsible for the preparation, issue, and interpretation of this procedure and of the referenced criteria.

Directors of Divisions having cognizance over equipment are responsible for implementation of this procedure and of the referenced criteria. This control is exercised by the Division Safety Officer.

The individual responsible for operation of equipment is responsible for compliance with this procedure and the referenced criteria and for informing the Division Safety Officer of any new operations or of changes in operations. This responsible individual shall obtain the Division Safety Officer's approval of purchase requisitions for controlled atmosphere chambers, to verify compliance with the criteria.

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D. Procedure

1. The criteria for design, construction, and operation of controlled atmosphere chambers intended for service at the Oak Ridge National Laboratory are presented in ORNL/TM-6865.

2. Determination of the service class an operation requires shall be made by the responsible individual and the Division Safety Officer, consulting with the Office of Operational Safety and/or others as appropriate. This determination and its basis shall be documented in a memorandum.

3. All new controlled atmosphere chambers shall be in compliance with the mandatory requirements of the criteria before being put in service.

4. Existing controlled atmosphere chambers shall be evaluated and:

   a. Verified as being in compliance with the mandatory requirements of the criteria,

   b. Brought into compliance with the mandatory requirements of the criteria, or

   c. A written justification for exception from the mandatory requirements of the criteria shall be submitted to and be accepted by the Division Safety Officer and the Office of Operational Safety.

   Compliance with one of the above options shall be achieved by December 31, 1980.

5. Before operation, the responsible individual shall satisfy the Division Safety Officer that all applicable requirements of these criteria have been satisfied, and specifically that the review and demonstration required by VII.1 and VII.2 of the criteria have been performed. Assistance may be obtained from the Office of Operational Safety or others as necessary. Conformance to the criteria shall be documented in a memorandum.

6. Crazed or cracked viewing windows shall be reported to the Division Safety Officer and to the Office of Operational Safety. At the earliest opportunity, damaged windows in Class A, Class B, or Class C chambers shall be replaced.

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Table 1

Classification of isotopes according to relative radiotoxicity based on inhalation hazard[a] amounts (curies) equivalent to one gram of Pu-239 (HEP)

Class 1 (Very high radiotoxicity) HEP ≤ 0.07	Sr-90 + Y-90, Po-210, Po-210 + Bi-210, Ra-226, Th-228, U-232, Np-236, Pu-238, Pu-239, Pu-240, Pu-241, Am-241, $Am-242_m$, Cm-242, Am-243, Cm-243, Cm-244, Cm-245, Cm-246, Cm-247, Bk-249, Cf-249, Cf-250, Cf-251, Cf-252
Class 2 (High radiotoxicity) HEP = 0.86-17	Na-22, P-32, Ca-45, Sc-46, V-48, Fe-59, Co-58, Co-60, Ni-63, Zn-65, Rb-86, Sr-89, Y-91, Zr-95 + Nb-95, Ru-103, Ru-106 + Rh-106, Ag-105, Ag-110, Cd-109 + Ag-109, Cd-115, In-114, Sn-113, Sb-122, Sb-124, Sb-125, I-131, Cs-134, Cs-137 + Ba-137, Ba-140 + La-140, Ce-144 + Pr-144, Pm-147, Sm-151, Eu-152, Eu-154, Tm-170, Hf-181, Ta-182, Ir-192, Hg-203, Tl-204, Bi-210, At-211, U-233,[b] Th-234 + Pa-234, Np-237, Pu-242
Class 3 (Moderate radiotoxicity) HEP = 22-220	Be-7, Na-24, S-35, K-42, Ca-47, Sc-47, Sc-48, Mn-52, Mn-54, Fe-55, Mn-56, Cu-64, Ga-72, As-74, As-76, As-77, Se-75, Br-82, Sr-85, Y-90, Nb-95, Mo-99, Pd-103 + Rd-103, Rh-105, Pd-109, Ag-111, Cd-115, Sb-122, Te-127, Ba-131, La-140, Ce-141, Pr-142, Pr-143, Nd-147, Ho-166, Sm-153, Ho-170, Lu-177, W-181, W-185, W-187, Re-183, Re-186, Os-191, Ir-190, Ir-192, Ir-194, Pt-191, Pt-193, Au-196, Au-198, Au-199, Hg-197, Tl-200, Tl-201, Tl-202, Ac-227, pure U-233, U-234
Class 4 (Slight radiotoxicity) HEP > 430	H-3, C-14, F-18, Cl-36, A-37, Cr-51, Ni-59, Ge-71, Kr-85, Tc-98, Tc-99, Ru-97, Rh-103, Te-129, I-129, I-132, Xe-133, Pb-203, U-235, U-236, Th-natural, U-238, U-natural

Refer to Procedure 1.5, Responsibility No. 6, for nuclear safety review criteria involving the underlined fissile isotopes.

[a]These values are based on inhalation and immersion (for inert gases) hazard only. Other factors that must be considered are criticality, chemical toxicity and reactivity, and pyrophoricity.

[b]≤500 ppm U-232.

$HEP = 2.16 \times 10^9\ MPC_a \times A$

MPC_a = μCi/cc for 40-hr wk

A = g/Ci or 0.1, whichever is greater.

Sample calculation — Determine curie HEP for Am-241.

MPC_a 40-hr week for Am-241 = 6×10^{-12} μCi/cc

Inverse specific activity (g/Ci) = .311

$\therefore HEP = 2.16 \times 10^9 \times 6 \times 10^{-12} \times .311$

$= 4.03 \times 10^{-3}$

Therefore, 4.03×10^{-3} curies of Am-241 has the same hazard equivalent potential as 1 gram of Pu-239.

Gram and curie HEP values for most isotopes are listed in Procedure 1.5 of this Manual.

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Table 2

Type of laboratory with quantity handled versus radiotoxicity

Radiotoxicity of isotopes	Type A	Type B	Type C	Type D
	High level laboratory	Radiochemical laboratory	Good chemical laboratory	Good chemical laboratory
Very high[a]	>10 mCi	10 μCi — 10 mCi	0.1 μCi — 10 μCi	0 — 0.1 μCi
High	>100 mCi	100 μCi — 100 mCi	0.1 μCi — 100 μCi	0 — 1.0 μCi
Moderate	>1 Ci	1 mCi — 1 Ci	10 μCi — 1 mCi	0 — 10 μCi
Slight	>10 Ci	10 mCi — 10 Ci	100 μCi — 10 mCi	0 — 100 μCi

[a]There is an upper limit to the quantity of transuranium elements which should be approved for glove box operations. As a general rule, for those isotopes having a gram HEP index number below 10^{-4}, the limiting quantity should be 100 mg. (For example, 100 mg of ^{244}Cm generates the same hazard equivalent potential as 4.3 kg of ^{239}Pu.) Any operation involving more than 100 mg of such isotopes should be conducted at facilities with more absolute containment features than are offered by glove boxes alone. This number may require further reduction due to penetrating radiation. One gram of ^{252}Cf, for example, generates a dose rate of 2400 rem/hr at a distance of one meter in air.

Definition of Laboratory Types — Unless otherwise stated, the requirements of basic laboratory or equal facility are understood.

Type A — Operations to be conducted in glove boxes or hot cells in facilities specifically constructed for handling high levels of radioactive materials. Containment features must prevent spread of activity within or release from the facility. Complete isolation (physical separation) from neighboring facilities, laboratories, offices, etc., is necessary. Glove boxes for this service shall comply with the requirements of the Glove Box Criteria document, ORNL/TM-6865.

Type B — Operations must be conducted in approved glove boxes. Glove boxes for this service shall comply with the requirements of the Glove Box Criteria Document, ORNL/TM-6865.

A degree of isolation such as hot change facilities or air locks to prevent spread of contamination to surrounding offices or laboratories must be maintained.

Type C — Operations must be conducted in approved chemical hoods which are vented through high efficiency filters. Hood openings must have a minimum face velocity of 100 fpm; however, 200 fpm may be required for various hazardous operations, especially if hot plates, aspirators, or Bunsen burners are used. Flame resistant Plexiglas (Type SE-3) may be used as a containment barrier for Type C laboratory operations provided approval of the Radiation Control Officer and Office of Operational Safety is obtained in advance.

Type D — Bench-top operation is normally satisfactory. Hood operations should be considered for upper levels of activity.

APPENDIX C

DESIGN OF VIEWING WINDOWS

The formulas used for calculating breaking strength of windows are developed from the conventional elastic-stress formulas for uniformly loaded simply supported circular and rectangular plates. The following simplified formulas were developed from the basic formulas, using appropriate values of modulus of rupture and of Poisson's Ratio for the different materials:

Pressure $\leqslant$ 6 in. w.g.

Circular —	Single thickness annealed glass:	$t=0.0047\ d\ \sqrt{F/S}$
	Single thickness tempered glass:	$t=0.0021\ d\ \sqrt{F/S}$
	Single thickness plastic:	$t=0.0028\ d\ \sqrt{F/S}$
	Laminated annealed glass:	$t=0.0033\ d\ \sqrt{F/S}$
	Laminated tempered glass:	$t=0.0015\ d\ \sqrt{F/S}$
Rectangular —	Single thickness annealed glass:	$t=0.021\ \gamma a\ \sqrt{F/S}$
	Single thickness tempered glass:	$t=0.0093\ \gamma a\ \sqrt{F/S}$
	Single thickness plastic:	$t=0.012\ \gamma a\ \sqrt{F/S}$
	Laminated annealed glass:	$t=0.015\ \gamma a\ \sqrt{F/S}$
	Laminated tempered glass:	$t=0.0066\ \gamma a\ \sqrt{F/S}$

Pressure > 6 in. w.g.

Circular —	Single thickness annealed glass:	$t=0.038\ d\ \sqrt{F/S}$
	Single thickness tempered glass:	$t=0.017\ d\ \sqrt{F/S}$
	Single thickness plastic:	$t=0.023\ d\ \sqrt{F/S}$
	Laminated annealed glass:	$t=0.027\ d\ \sqrt{F/S}$
	Laminated tempered glass:	$t=0.012\ d\ \sqrt{F/S}$
Rectangular —	Single thickness annealed glass:	$t=0.171\ \gamma a\ \sqrt{F/S}$
	Single thickness tempered glass:	$t=0.077\ \gamma a\ \sqrt{F/S}$
	Single thickness plastic:	$t=0.099\ \gamma a\ \sqrt{F/S}$
	Laminated annealed glass:	$t=0.121\ \gamma a\ \sqrt{F/S}$
	Laminated tempered glass:	$t=0.054\ \gamma a\ \sqrt{F/S}$

t is thickness of <u>each</u> layer,
d is the diameter of a circle, and
a is length of the short side of a rectangle:
all dimensions in inches.

Values of γ have been computed for Poisson's Ratio of 0.20 (glass) and of 0.40 (plastic), and are presented in Fig. 1. Figure 2 indicates the upper limits of the dimensions of rectangular windows made of 1/4 in. thick safety plate (laminated) glass and subjected to $\leqslant$6 in. w.g. Figure 3 indicates the upper limits of the dimensions of rectangular windows without glove ports, made of 1/4 in. thick Lexan plastic and subjected to $\leqslant$6 in. w.g. Figure 4 indicates the upper limits of the dimensions of rectangular windows with glove ports, made of 1/4 in. thick Lexan plastic and subjected to $\leqslant$6 in. w.g.

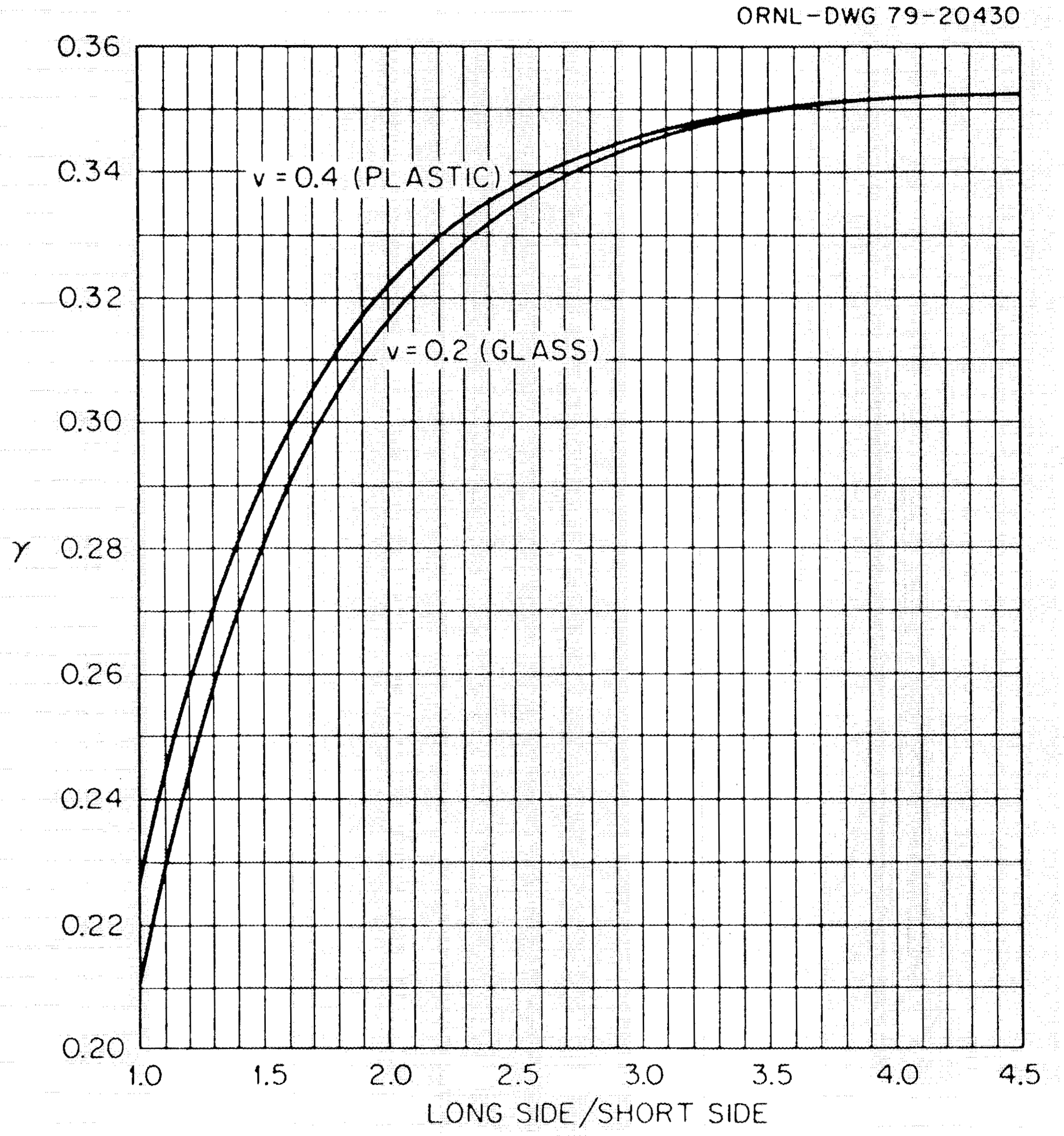

Fig. 1. Values of γ for glass and plastic for different geometrical ratios.

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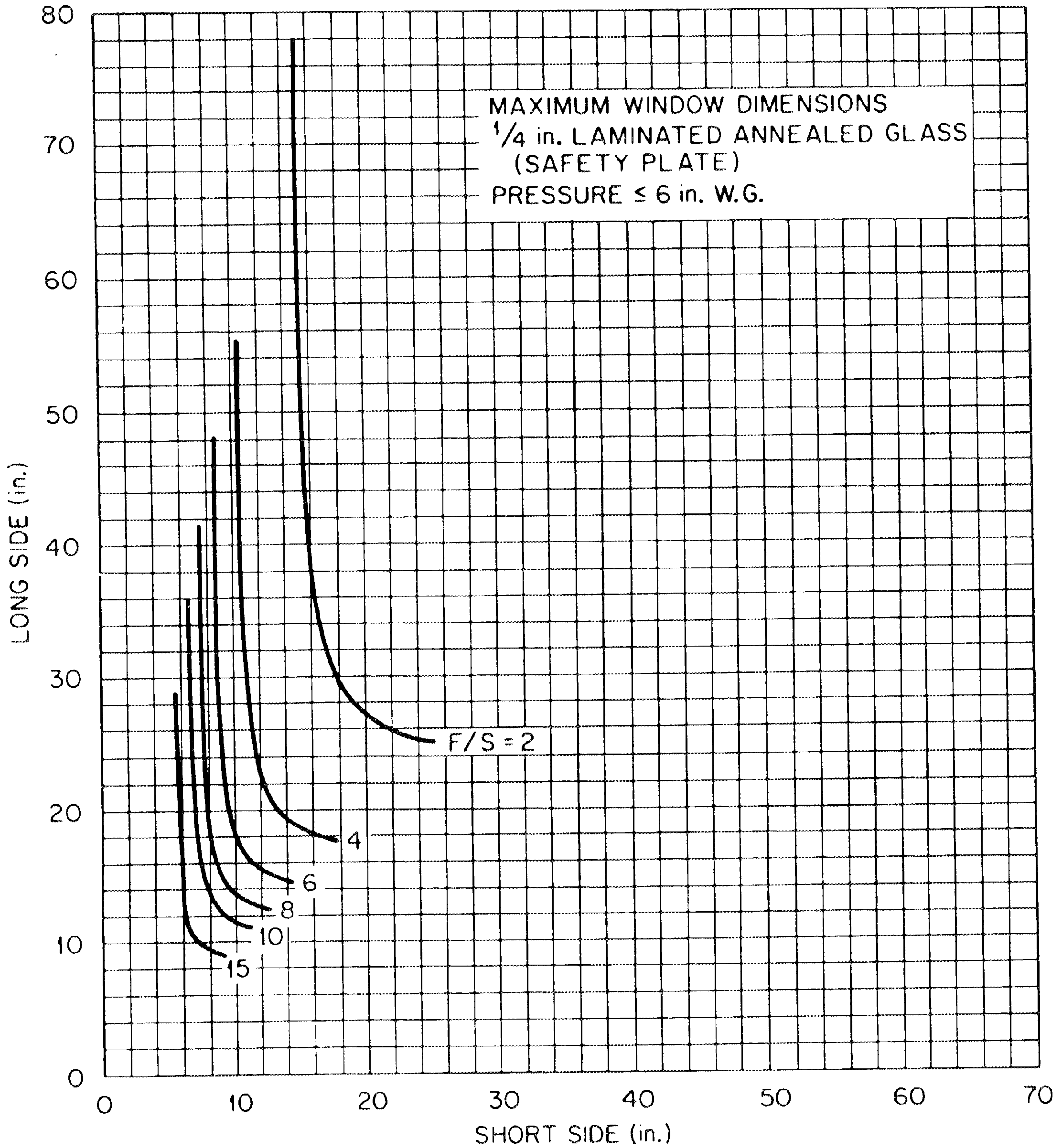

Fig. 2. Maximum window dimensions for windows made of 1/4 in. thick laminated safety glass.

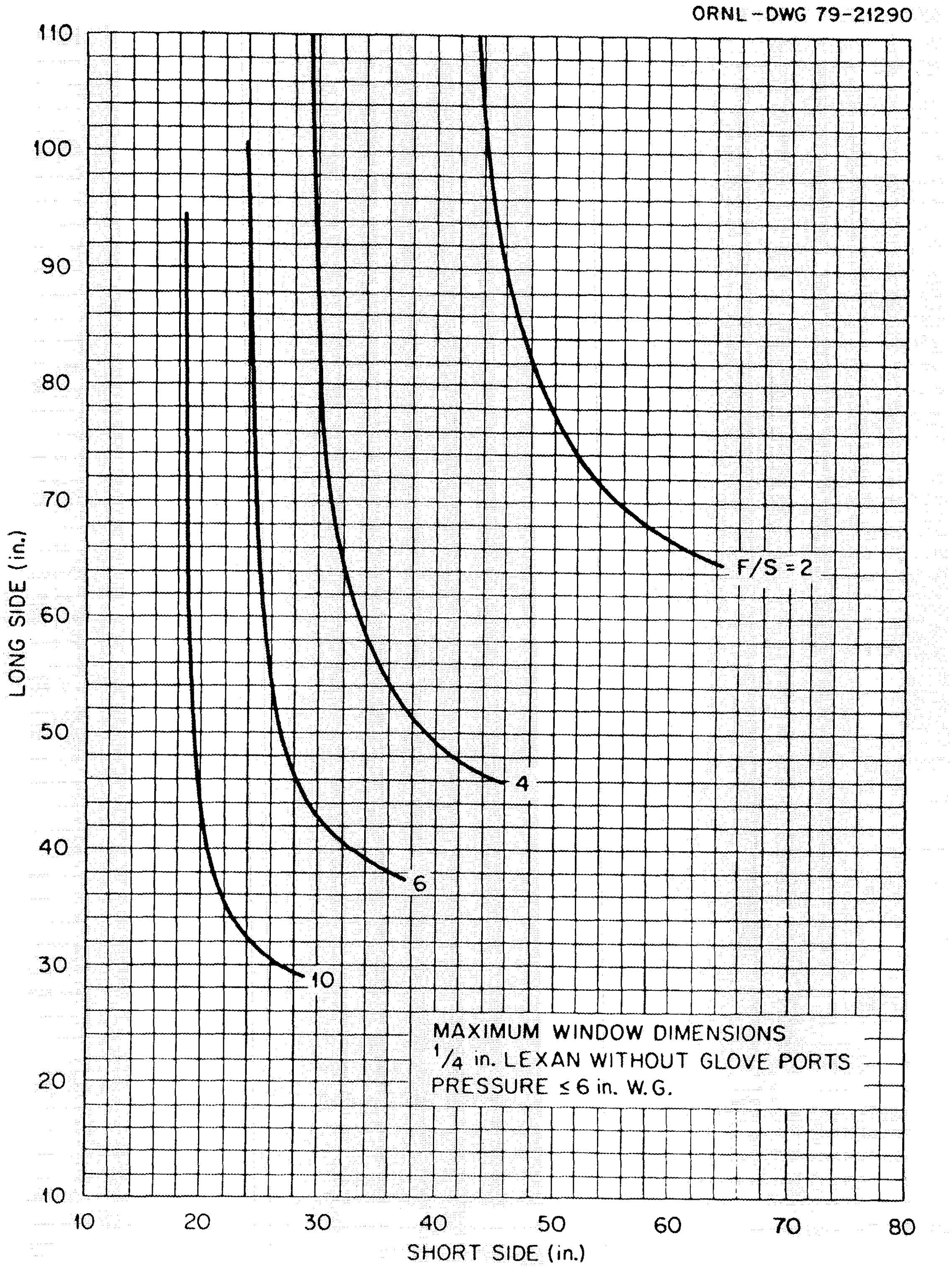

Fig. 3. Maximum window dimensions for windows made of 1/4 in. thick lexan without glove ports.

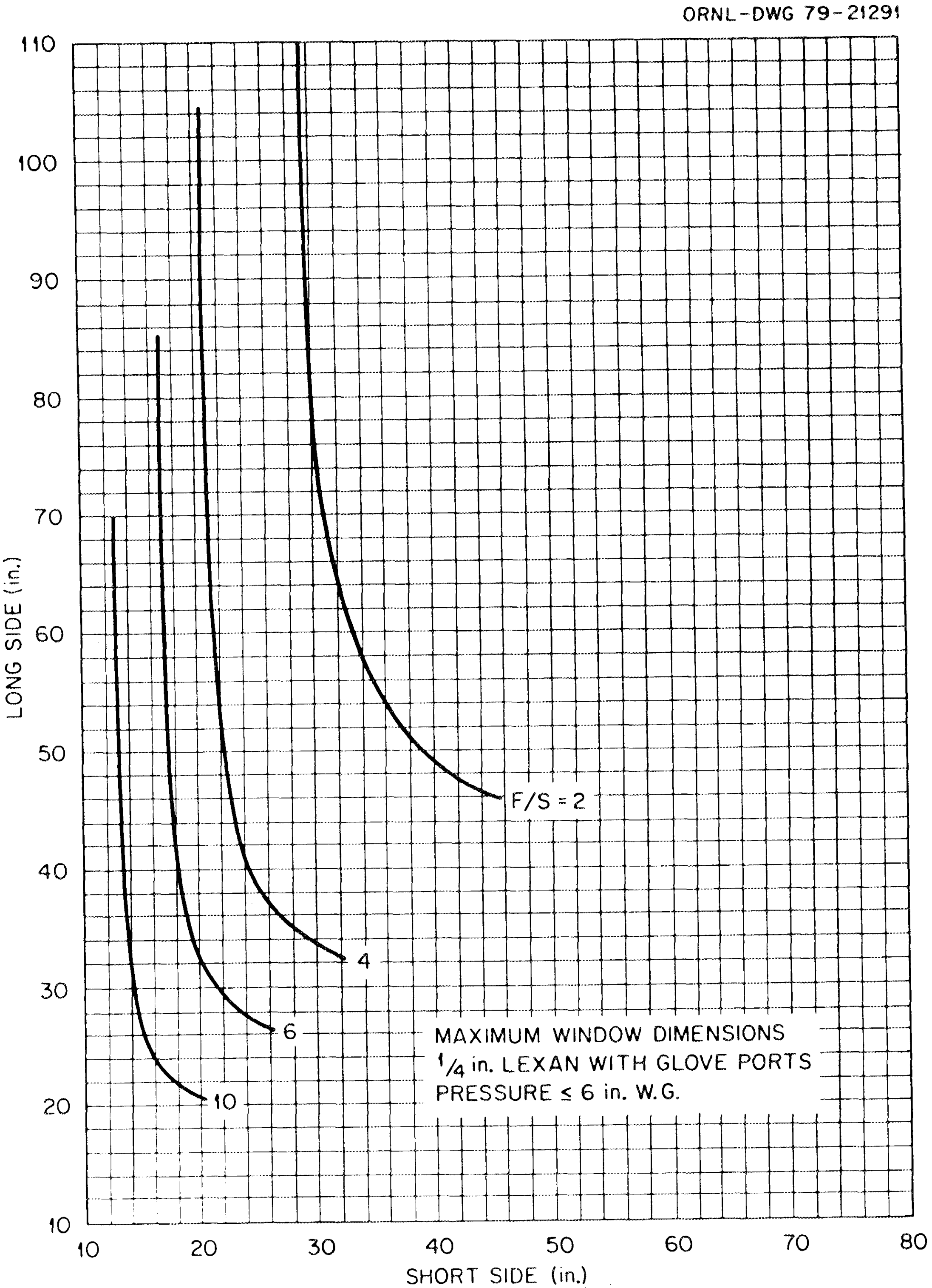

Fig. 4. Maximum window dimensions for windows made of 1/4 in. thick lexan with glove ports.

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