ATOMIC INDUSTRIAL FORUM, INC.

June 6, 1961

Mr. Harold L. Price
Acting Director of Regulation
U. S. Atomic Energy Commission
Washington 25, D. C.

Dear Mr. Price:

Subsequent to the March 17 meeting of the Forum's Committee on Reactor Safety at which time the AEC's proposed site criteria were reviewed, it was determined that it might be more helpful to the AEC if the group were to incorporate its comments in a redraft of the criteria. Accordingly, a working group was designated to undertake this assignment and we are enclosing herewith two copies of the working group's suggested redraft.

The working group was chaired by D. Roy Shoults of General Electric Co. and included Roger Coe of Yankee Atomic Electric Co., W. Kenneth Davis of Bechtel Corp., James Fairman of Consolidated Edison Co. of New York, Inc., John Gray of Nuclear Utilities Services, Inc., Woodrow Johnson of Westinghouse Electric Corp., and Harold Vann of Jackson & Moreland, Inc. The suggested redraft reflects the views of the individuals on the working group but does not necessarily reflect the views of the companies with which they are affiliated.

The redrafted criteria have been prepared in two different formats: (1) a version which for purposes of comparison includes both the AEC and AIF proposals in their entirety, and (2) a version including only the AIF proposal.

The members of the Forum Committee's working group believe that the AEC proposed guides have already served a useful purpose inasmuch as they have focused timely attention on and have stimulated public thinking on the important problem of reactor siting. The group further believes that the adoption by the AEC of site criteria guides can serve a useful and desirable purpose provided:

1. The guides give due recognition to the importance of the engineering design of a proposed reactor as well as to the population density and use characteristics of the site environs and to the physical characteristics of the proposed site; and

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2. The guides are sufficiently flexible to accommodate and take advantage of such new information as may be gained from the experience of constructing and operating nuclear power reactors.

Also, the Committee has accepted without comment the radiation exposure limits specified in the AEC proposed guides for the exclusion area and low population zone. The Committee members do not regard themselves qualified to make a judgment on the radiation limits that should be set for such a low probability, once-in-a-lifetime accidental or emergency exposure. The Committee has, however, noted with assurance that the specified limits have been derived from limits suggested by the National Committee on Radiation Protection and Measurements and that the AEC believes them to be conservative values.

The redrafted criteria are largely based on the comments produced by our March 17 meeting, a summary of which was enclosed in my letter to you of April 6. In brief, the redraft would:

1. limit the applicability of the criteria only to power reactors.

2. assure that the example calculation would not be considered an integral part of the criteria. In our opinion, example calculations should not be published as part of the guides. We do believe that it would be useful to publish them in the scientific literature, e.g., the AEC Journal of Reactor Safety. In an effort however, to be consistent with the AEC proposed criteria, we have included four examples in Appendix A and referred to them in the criteria only in a note. We believe that the use of multiple examples, (one of which is identical to that contained in the AEC proposed criteria) will emphasize a range of possible design-site relationships and that a proposed site can be evaluated only in connection with the engineering features of the proposed reactor. The criteria would also make it clear that the calculations submitted by an applicant in support of a request for site approval must be submitted in terms of the reactor type, design and size proposed, and the population and physical characteristics of the site proposed.

3. delete the population center distance concept on the premise that any additional distance factor determined by multiplying the low population radius by the arbitrary value of 1-1/3 is without technological basis. We suggest that this concept should be replaced by a man-rem radiation exposure limit to be expressed as a function of population distribution and density. The AEC or Federal Radiation Council should undertake to develop such a concept.

4. focus more attention on the importance of the interrelationship between design, site characteristics, distance, and population density.

If the suggestions contained in the Forum Committee's draft were to be accepted, it would necessitate the incorporation of certain modifications in the "Statement of Considerations." We should also like to call your attention again to the criticism of the statement of considerations contained in the summary of our March 17 meeting. You will recall our suggestion to delete objective (b) and to modify objective (a) to read: "Serious or fatal injury to individuals ......"

The importance assigned by the Forum Committee to the problem of site criteria is manifested by the interest and effort it has shown in preparing a document which we hope will prove of assistance to the AEC. Indeed, we cannot over-emphasize the impact which we believe the establishment of site criteria will have on reactor development in the U. S. and on friendly nations abroad who look to the U. S. to set precedents in such important policy areas. Reasonable site criteria must be established which will meet the needs of public safety, establish and maintain public confidence, support our prestige and leadership overseas, and permit the development of atomic power as rapidly as technological development and economic incentives warrant.

If we can be of any further assistance to the AEC in this important problem area, please let us know.

Sincerely yours,

/s/ W. Kenneth Davis, Chairman
Committee on Reactor Safety

WKD:ds
Enclosures

cc: Robert Lowenstein
Clifford Beck

ATOMIC INDUSTRIAL FORUM

Reactor Site Criteria

The following represents a modified version of the AEC's "Notice of Proposed Guides - Reactor Site Criteria," 10 CFR, Part 100, published in the February 11, 1961, issue of the Federal Register. It has been prepared by the Atomic Industrial Forum's Committee on Reactor Safety.

In the interest of clarity and to facilitate comparison of the AEC and AIF proposals, both appear here in their entirety. Also included are brief explanations of suggested modifications. Attention is called to the following reading key.

Reading Key: The copy in the regular double-spaced type appears in the AEC proposed criteria and is to be retained in the AIF suggested criteria.

The copy in capitals appears in the AEC proposed criteria but is to be deleted in the AIF suggested criteria.

The underlined copy represents substitute or additional copy to appear in the AIF suggested criteria.

The single-spaced copy in brackets at the end of each paragraph gives the reasons for the changes, deletions and/or additions in the paragraph immediately above.

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General Provisions

100.1 Purpose. It is the purpose of this part to describe the criteria which guide the Commission in its evaluation of the suitability of proposed sites for power AND TESTING reactors subject to Part 50 of this chapter. BECAUSE IT IS NOT POSSIBLE TO DEFINE SUCH CRITERIA WITH SUFFICIENT DEFINITENESS TO ELIMINATE THE EXERCISE OF AGENCY JUDGMENT IN THE EVALUATION OF

THESE SITES, THIS PART IS INTENDED PRIMARILY TO IDENTIFY A NUMBER OF FACTORS CONSIDERED BY THE COMMISSION AND THE GENERAL CRITERIA WHICH ARE UTILIZED AS GUIDES IN APPROVING OR DISAPPROVING PROPOSED SITES. Insufficient experience has been accumulated to permit the writing of standards, which will correlate a reactor site with the design and intended use of the reactor, or to preclude the exercise of judgment by the applicant and the agency in the evaluation of reactor sites. This part is intended to identify a number of factors considered by the Commission and the general criteria which are to be utilized only as interim guides in evaluating proposed sites.

/The statement of purpose should imply that reactor site evaluation may eventually be based on widely recognized and accepted standards. The importance of reactor design should be recognized in the statement of purpose. The "applicant" as well as the "agency" should exercise judgment. It should be clearly stated that these are "guides" to be used as guides and that they are of an interim nature./

100.2 Scope. This part applies to applications filed under Part 50 of this chapter FOR CONSTRUCTION PERMITS AND OPERATING LICENSES for power reactors.

/Although the AEC's authority to disapprove a site at any stage of reactor construction or operation is recognized, it appears gratuitous to suggest that the adequacy of the site must be demonstrated again after construction of a facility has been completed in conformance with an AEC-issued construction permit. It is assumed that the suggested deletion in no way alters the scope of the guides or the intent of the AEC./

The site criteria contained in this part apply primarily to reactors of a general type and design on which experience has been developed, but can also be applied with ADDITIONAL CONSERVATISM TO OTHER REACTORS appropriate modifications to other reactor types.

FOR REACTORS WHICH ARE NOVEL IN DESIGN, UNPROVEN AS PROTOTYPES, AND DO NOT HAVE ADEQUATE THEORETICAL AND EXPERIMENTAL OR PILOT PLANT EXPERIENCE, THESE CRITERIA WILL NEED TO BE APPLIED MORE CONSERVATIVELY. THIS CONSERVATISM WILL RESULT IN MORE ISOLATED SITES-- THE DEGREE OF ISOLATION REQUIRED DEPENDING UPON THE LACK OF CERTAINTY AS TO THE SAFE BEHAVIOR OR THE REACTOR. IT IS ESSENTIAL, OF COURSE, THAT THE REACTOR BE CAREFULLY AND COMPETENTLY DESIGNED, CONSTRUCTED, OPERATED, AND INSPECTED.

/_The implication of the material to be deleted is that a reactor of "novel design" cannot be as safe or safer than a reactor "of a general type and design on which experience has been developed," which is not necessarily the case. It is unfortunately inferred that "conservatism" and and "isolation" are analogous. The last sentence appears gratuitous and without purpose._/

100.3 Definitions. As used in this part:

(a) "Exclusion area" means the area surrounding the reactor, access to which is under the full control of the reactor licensee. This area may be traversed by a highway, railroad, or waterway, provided these are not so close to the facility as to interfere with normal operations, and provided appropriate and effective arrangements are made to control traffic on the highway, railroad, or waterway, in case of emergency, to protect the public health and safety. Residence within the exclusion area shall normally be prohibited. In any event, residents shall be subject to ready removal in case of necessity. Activities unrelated to operation of the reactor may be permitted in an exclusion area under appropriate limitations, provided that no significant hazards to the public health and safety will result.

/_No change._/

(b) "Low population zone" means the area immediately surrounding the exclusion area which contains residents the total number and density of which is such that there is a reasonable probability that appropriate protective measures could be taken in the event of a serious accident. These guides do not specify a permissible population density or total population within this zone because the situation may vary from case to case. Whether a specific number of people can, for example, be evacuated from a specific area, or instructed to take shelter, on a timely basis will depend on many factors such as location, number and size of highways, scope and extent of advance planning, and actual distribution of residents within the area.

/No change./

(c) "POPULATION CENTER DISTANCE" MEANS THE DISTANCE FROM THE REACTOR TO THE NEAREST BOUNDARY OF A DENSELY POPULATED CENTER CONTAINING MORE THAN ABOUT 25,000 RESIDENTS.

/The above definition has been deleted in conformance with the deletion of the "population center distance" concept in Section 100.11./

(d) "Power reactor" means a nuclear reactor of a type described in Sections 50.21 (b) or 50.22 of Part 50 of this chapter designed to produce electrical or heat energy.

/No change./

(e) "TESTING REACTOR" MEANS A "TESTING FACILITY" AS DEFINED IN SECTION 50.2 OF PART 50 OF THIS CHAPTER.

/Testing reactors are designed for experimental operations and should not be evaluated under these criteria./

Site Evaluation Factors

100.10 Factors to be Considered When Evaluating Sites. In determining the acceptability of a site for a power OR TESTING reactor, the Commission will take the following factors into consideration:

/No change./

(a) Characteristics of reactor design and operation including:

(i) Intended use of the reactor including the proposed maximum power level and the nature and inventory of contained radioactive materials.

(ii) Physical characteristics of the proposed reactor type, especially those bearing on safe operation and maintenance such as reactivity coefficients, heat capacity and transfer characteristics of fuel and core, and shutdown margin of reactivity.

(iii) Provision of such auxiliary safety systems as decay heat removal systems, emergency core cooling system, poison injection system and emergency condenser system.

(iv) Integrity of reactor components and facilities to contain transient pressures and potential releases of radioactive material such as fuel cladding, pressure vessel, primary shielding, and biological shielding and the extent to which reactor design incorporates well proven engineering standards.

(v) Type and integrity of reactor containment and method of operation during power operation and shutdown including provisions for such procedures as reducing pressure, controlling and disposing of leakage, and reducing concentration of contained fission products.

/ The above section has been added on the premise that it is impossible to evaluate a site without a prior assessment of reactor design. It should also be recognized that most reactor systems have built into them four different lines of safety defense as enumerated in (ii), (iii), (iv) and (v) above which have to be breached as the result of an incident or accident before a safety problem can arise. /

(b) Population density and use characteristics of the site environs, including, among other things, the exclusion area and low population zone AND POPULATION CENTER DISTANCE.

/ The deletion is in conformance with the deletion of the "population center distance" concept in Section 100.11. The order of entry has also been changed, i.e. this was item (a) in the AEC proposal. /

(c) Physical characteristics of the site, including, among other things, seismology, meteorology, geology and hydrology. For example:

(i) The design for the facility should conform to accepted building codes or standards for areas having equivalent earthquake histories. No facility should be located closer THAN 1/4 TO 1/2 MILE than 1/4 mile from the surface location of a known active earthquake fault but in all cases, consideration should be given to the character of the fault and the type of soil or rock providing the foundation for the reactor plant.

(ii) Meteorological conditions at the site and in the surrounding area SHOULD BE CONSIDERED.

(iii) Geological and hydrological characteristics of the proposed site may have a bearing on the consequences of an escape of radioactive material from the facility.

UNLESS SPECIAL PRECAUTIONS ARE TAKEN, REACTORS SHOULD NOT BE LOCATED AT SITES WHERE RADIO-ACTIVE LIQUID EFFLUENTS MIGHT FLOW READILY INTO NEARBY STREAMS OR RIVERS OR MIGHT FIND READY ACCESS TO UNDERGROUND WATER TABLES. Special precautions should be taken if a reactor is to be located at a site where a significant quantity of radio-active liquid effluents might flow readily into nearby

<u>streams or rivers or might find ready access to underground water tables.</u>

<u>The physical characteristics of a site must be evaluated in close conjunction with a safety assessment of the engineering characteristics of the reactor to be located on the site.</u>

Where some unfavorable physical characteristics of the site exist, the proposed site may nevertheless be found to be acceptable if the design of the facility includes appropriate and adequate compensating engineering safeguards.

/The above changes are designed to represent a positive way of stating what was apparently intended in the comparable sections of the AEC proposal. The order of entry has also been changed, i.e. this was item (b) in the AEC proposal./

(c) CHARACTERISTICS OF THE PROPOSED REACTOR, INCLUDING PROPOSED MAXIMUM POWER LEVEL, USE OF THE FACILITY, THE EXTENT TO WHICH THE DESIGN OF THE FACILITY INCORPORATES WELL PROVEN ENGINEERING STANDARDS, AND THE EXTENT TO WHICH THE REACTOR INCORPORATES UNIQUE OR UNUSUAL FEATURES HAVING A SIGNIFICANT BEARING ON THE PROBABILITY OR CONSEQUENCES OF ACCIDENTAL RELEASES OF RADIOACTIVE MATERIAL.

/These provisions in their entirety are now incorporated in Section (a)./

100.11 Determination of Exclusion Area and Low Population Zone AND POPULATION CENTER DISTANCE.

(a) AS AN AID IN EVALUATING A PROPOSED SITE, AN APPLICANT SHOULD ASSUME A FISSION PRODUCT RELEASE FROM THE CORE AS ILLUSTRATED IN APPENDIX "A", THE EXPECTED DEMONSTRABLE LEAK RATE FROM THE CONTAINMENT, AND METEOROLOGICAL CONDITIONS PERTINENT TO HIS SITE TO DERIVE AN EXCLUSION AREA, A LOW POPULATION ZONE AND A POPULATION CENTER DISTANCE. FOR THE PURPOSE OF THIS ANALYSIS, THE APPLICANT SHOULD DETERMINE THE FOLLOWING:

/This section has been rewritten with a different format to remove Appendix "A" as an integral part of the guides. Most of the other points enumerated above are contained in (b) below./

(a) The applicant should estimate an exclusion area and a low population zone which are defined as follows:

(i) An exclusion area shall be of such size that an individual located at any point on its boundary for two hours immediately following onset of the POSTULATED FISSION PRODUCT RELEASE estimated release of radioactive material would not receive a total radiation dose to the whole body in excess of 25 rem or a total radiation dose in excess of 300 rem to the thyroid from iodine exposure.

(ii) A low population zone shall be of such size that an individual located at any point on its outer boundary who is exposed to THE RADIOACTIVE CLOUD RESULTING FROM

THE POSTULATED FISSION PRODUCT RELEASE (DURING THE ENTIRE PERIOD OF ITS PASSAGE) the released radioactive material (during the entire incident) would not receive a total radiation dose to the whole body in excess of 25 rem or a total radiation dose in excess of 300 rem to the thyroid from iodine exposure.

Note: The whole body dose of 25 rem referred to above corresponds to the once in a lifetime accidental or emergency dose for radiation workers which, according to NCRP recommendations, may be disregarded in the determination of their radiation exposure status. (See addendum dated April 15, 1958 to NBS Handbook 59) The NCRP has not published a similar statement with respect to portions of the body, including doses to the thyroid from iodine exposure. For the purpose of establishing areas and distances under the conditions assumed in these guides, the whole body dose of 25 rem and the 300 rem dose to the thyroid from iodine are believed to be conservative values.

(b) In estimating an exclusion area and a low population zone to meet the above prerequisites, an applicant, taking into account the type and design of the proposed reactor, the number and type of safety features incorporated in the design, and other pertinent factors, should consider:

(i) The extent of fission product release from the primary reactor system, which normally will be based on an assumed rupture of the primary loop and loss of coolant followed by substantial melting of the core. It is assumed that these circumstances could lead to the release of an appreciable portion of the fission gases and halogens containe in the core.

(ii) The extent of halogen absorption within the containment system, even in the absence of safety systems specifically designed to remove halogens and other fission products. Credit can be taken for the provision of such halogen and fission product removal systems.

(iii) The extent of long-term leakage from the containment system as a function of time based on the extimated integrity of the containment system to be demonstrated as a function of pressure and time. Credit can be taken for safety systems specifically designed to reduce the pressure within the containment system and for fission product decay.

(iv) The meteorological conditions of atmospheric dispersion pertinent to the site, assuming the probable worst or least favorable weather conditions. In estimating the size of the exclusion area, the worst weather conditions experienced at the proposed site for periods of two to six hours at intervals of two to three times per year should be used. In extimating the size of the low population zone, the worst weather conditions experienced at the proposed site for periods of two to six days at intervals of two to three times per year should be used. Account should be taken of the point of release of radioactive material, that is, whether at ground level or from a stack of what effective height.

(v) The estimated radiation exposure resulting from direct gamma radiation from the containment system as compared with the estimated radiation exposure resulting from the radioactive iodine contained in any plume of radioactive material escaping from the containment system. The larger estimated radiation exposure should be used in determining the size of the exclusion area.

/The above material has been added with the thought that it will aid an applicant in having outlined some of the factors that the AEC considers important in determining the size of an exclusion area and low population zone./

(c) A POPULATION CENTER DISTANCE OF AT LEAST 1-1/3 TIMES THE DISTANCE FROM THE REACTOR TO THE OUTER BOUNDARY OF THE LOW POPULATION ZONE. IN APPLYING THIS GUIDE DUE CONSIDERATION SHOULD BE GIVEN TO THE POPULATION DISTRIBUTION WITHIN THE POPULATION CENTER. WHERE VERY LARGE CITIES ARE INVOLVED, A GREATER DISTANCE MAY BE NECESSARY BECAUSE OF TOTAL INTEGRATED POPULATION DOSE CONSIDERATIONS.

/A population center distance determined by multiplying the distance from the reactor to the outer boundary of the low population zone by 1-1/3 appears to be without technological basis. If an additional distance factor, supplementing those afforded by the exclusion area and the low population zone, were deemed necessary, it would be more meaningful and understandable as well as more in keeping with the exclusion area and low population zone concepts to incorporate a man-rem radiation exposure limit as a function of population distribution and density./

(b) APPENDIX "A" OF THESE GUIDES CONTAINS AN EXAMPLE OF A CALCULATION FOR HYPOTHETICAL REACTORS WHICH CAN BE USED AS AN INITIAL ESTIMATE OF THE EXCLUSION AREA, THE LOW POPULATION ZONE, AND THE POPULATION CENTER DISTANCE.

THE CALCULATIONS DESCRIBED IN APPENDIX "A" ARE A MEANS OF OBTAINING PRELIMINARY GUIDANCE. THEY MAY BE USED AS A POINT OF DEPARTURE FOR CONSIDERATION OF PARTICULAR SITE REQUIREMENTS WHICH MAY RESULT FROM EVALUATIONS OF THE PARTICULAR CHARACTERISTICS OF THE REACTOR, ITS PURPOSE, METHOD OF OPERATION, AND SITE INVOLVED. THE NUMERICAL VALUES STATED FOR THE VARIABLES LISTED IN APPENDIX "A" REPRESENT APPROXIMATIONS THAT PRESENTLY APPEAR REASONABLE, BUT THESE NUMBERS MAY NEED TO BE REVISED AS FURTHER EXPERIENCE AND TECHNICAL INFORMATION DEVELOPS.

/An appendix containing an example calculation should not be made an integral part of these guides. The "results" derived from a single example calculation, whether intended or not, take on such significance as to obscure the intent of the guides. Indeed, a single example, incorporated into the guides as proposed by the AEC effectively substitutes the example calculation for the guides, thereby imposing upon applicants an arbitrary set of circumstances which in most instances will neither conform to the applicant's site characteristics nor to the characteristics of his proposed reactor facility./

(c) <u>In determining the size of an exclusion area to contain multiple reactors, consideration should be given to the following:</u>

(i) <u>If the reactors are in no way interconnected so that the possibility of an incident or accident in one reactor initiating an incident in, or causing damage to, another</u>

reactor is negated, the size of the exclusion area shall be based on the largest single reactor of similar types or if different types of reactors are involved, on the reactor which could conceivably release the greatest amount of radioactive material.

(ii) If the reactors are interconnected in a manner that could effect the safety of either, the size of the exclusion area shall be based on assuming that all interconnected reactors constitute a single reactor of a size equivalent to the sum of the power ratings of each.

[It is believed that these guides should anticipate the siting of multiple reactors in the same location.]

(d) These guides do not consider the disposition of a reactor which which has experienced an incident or accident resulting in the release of radioactive material. Nothing in these guides, however, is intended to preclude the continued operation of other nuclear and non-nuclear facilities located on the same site.

[It is believed that these guides should not be silent on the disposition of a reactor which has experienced an incident or accident resulting in the release of radioactive material.]

Note: As a possible aid to an applicant, Appendix "A" of these guides contains sample calculations for several hypothetical reactors and sites. Applicants are cautioned that calculations in support of a request for site approval must be submitted to the Commission in the specific terms of the reactor type, design and size, and the population and physical characteristics of the site, which are to be

<u>enumerated in the license application.</u>

/It is acknowledged that sample calculations might prove of assistance to some applicants. Such calculations, however, should show a range of design-site relationships and make it clear that a proposed reactor site can be evaluated only after careful consideration of the engineering and safety features of the proposed reactor and cannot be made on the basis of distance alone./

APPENDIX "A-1"

Example of a Calculation of Reactor Siting Distances

1. The calculations of this Appendix are based upon the following assumptions:

   a. The fission product release to the atmosphere of the reactor building is 100% of the noble gases, 50% of the halogens and 1% of the solids in the fission product inventory. This release is equal to 15.8% of the total radioactivity of the fission product inventory. Of the 50% of the halogens released, one-half is assumed to adsorb onto internal surfaces of the reactor building or adhere to internal components.

   b. The release of radioactivity from the reactor building to the environment occurs at a leak rate of 0.1% per day of the atmosphere within the building and the leakage rate persists throughout the effective course of the accident which, for practical purposes, is until the iodine activity has decayed away.

   c. In calculating the doses which determine the distances, fission product decay in the usual pattern has been assumed to occur during the time fission products are contained within the reactor building. No decay was assumed during the transit time after release from the reactor building.

   d. No ground deposition of the radioactive materials that leak from the reactor building was assumed.

   e. The atmospheric dispersion of material leaking from the reactor building was assumed to occur according to the following relationship:

$$X = \frac{Q}{\pi u \sigma y \sigma z}$$

   where Q is rate of release of radioactivity from the containment vessel, the ("source term,"):

   x - is the atmospheric concentration of radioactivity at distance d from the reactor,

   u - is the wind velocity,

   σy and σz - are horizontal and vertical diffusion parameters respectively.

   f. Meteorological conditions of atmospheric dispersion were assumed to be those which are characteristic of the average "worst" (least favorable) weather conditions for average meteorological regimes over the country. For the purposes of these calculations, the parameters used in the equation in section e. above were assigned the following values:

   see next page

Appendix "A-1"

$$u = 1\text{m/sec} \qquad \sigma\bar{y} = [1/2Cy^2d^{2-n}]^{\frac{1}{2}}$$

$$\sigma\bar{u} = [1/xCz^2d^{2-n}]^{\frac{1}{2}} \qquad Cy = .40 \qquad Cz = 0.07 \qquad n = 0.5$$

g. The isotopes of iodine were assumed to be controlling for the low population zone distance. The low population zone distance results from integrating the effects of iodine-131 through -135.

h. The source strength of each iodine isotope was calculated to be as follows:

Isotope	Exclusion Q (curies/megawatt)	Low population Q (curies/megawatt)
I-131	0.55	76.4
I-132	0.68	1.40
I-133	1.19	18.5
I-134	0.72	0.91
I-135	1.04	5.4

These source terms conbine the effects of fission yield under equilibrium conditions, radioactive decay in the reactor building, and the release rate from the reactor building, all integrated throughout the exposure time considered.

i. For the exclusion distance, doses from both direct gamma radiation and from iodine in the cloud escaping from the reactor building were calculated, and the distance established on the basis of the effect requiring the greater isolation.

j. In calculating the thyroid doses which result from exposure of an individual to an atmosphere containing concentrations of radioactive iodine, the following conversion factors were used to determine the dose received from breathing a concentration of one curie per cubic meter for one second:

Isotope	Dose (rem)
I-131	329.0
I-132	12.4
I-133	92.3
I-134	5.66
I-135	25.3

k. The whole body doses at the exclusion and low population zone distances due to direct gamma radiation from the fission products released into the reactor building were derived from the following relationships:

$$D = 483 \frac{Be^{-ur}}{4\pi r}2 \int_0^t t^{-0.21}dt$$

where D is the exposure dose in roentgens per megawatt of reactor power,

r - is the distance in meters,

B - the scattering factor - is equal to $(1 = ur - \frac{(ur)^2}{3})$,

u - is the air attenuation factor (0.01 for this calculation),

t - is the exposure time in seconds.

In this formulation, it was assumed that the shielding and building structures provided an attenuation factor of 10.

2. On the basis of calculation methods and values of parameters described above, initial estimates of distances for reactors of various power levels have been developed and are listed below.

Power Level Thermal Megawatt	Exclusion Distance miles	Low Population Zone Distance miles
1500	.70	13.3
1200	.60	11.5
1000	.53	10.0
900	.50	9.4
800	.46	8.6
700	.42	8.0
600	.38	7.2
500	.33	6.3
400	.29	5.4
300	.24	4.5
200	.21	3.4
100	.18	2.2
50	.15	1.4
10	.08	0.5

APPENDIX "A-2"

Example of a Calculation of Reactor Siting Distances

1. The calculations of this appendix have been made in accordance with the approach used in "Appendix A" of the "Notice of Proposed Guides - Reactor Site Criteria" 10 CFR, Part 100, as published February 11, 1961, and the fission product release data from the core of the reactor are identical to those assumed in the Guides. The specific plant calculated is a 600 Mw thermal pressurized water type of reactor to be constructed in an irregular rolling land area. It is assumed that the containment vessel is completely surrounded by a concrete shield and roof and that the annular space between the containment vessel and shield is ventilated to a stack so that all containment vessel leakage is discharged at the top of the stack. Provision is also made for heating of the stack to achieve additional atmospheric dispersion.

The calculations of this appendix are based upon the following assumptions:

a. The fission product release to the atmosphere of the reactor building is 100% of the noble gasses, 50% of the halogens and 1% of the solids in the fission product inventory. This release is equal to 15.8% of the total radioactivity of the fission product inventory. Of the 50% of the halogens released, one-half is assumed to adsorb onto internal surfaces of the reactor building or adhere to internal components.

b. The release of radioactivity from the reactor building to the environment occurs at a leak rate of 0.1% per day of the atmosphere within the building and the leakage rate decreases because of pressure reduction throughout the effective course of the accident which, for practical purposes, is until the iodine activity has decayed away. The release to the environs is however through a stack at an elevation of 100 M above grade. Further engineering of the plant has assured that the stack may be heated so that the effective stack height is 300 M.

c. In calculating the doses which determine the distances, fission product decay in the usual pattern has been assumed to occur during the time fission products are contained within the reactor building. No decay was assumed during the transit time after release from the reactor building.

d. No ground deposition of the radioactive materials that leak from the reactor building was assumed.

e. The atmospheric despersion of material leaking from the reactor building was assumed to occur according to the following relationship:

Appendix "A-2"

$$x = \frac{Q}{\pi u \ \sigma y \ \sigma z} e^{-H}$$

Where Q is rate of release of radioactivity from the containment vessel, the ("source term"):

x - is the atmospheric concentration of radioactivity at distance d from the reactor.

u - is the wind velocity.

σy and σz - are horizontal and vertical diffusion parameters respectively.

e^{-H} - is the height of release reduction parameter.

H - is equal to $\frac{h^2}{C_z^2 \ d^{2-h}}$ where h = effective stack height.

f. Meteorological conditions of atmostpheric dispersion were assumed to be those that are characteristic of inversion conditions (unfavorable) for the meteorological regimes over irregular rolling land which is characteristic of the site under consideration. For the purposes of these calculations, the parameters used in the equation in Section (e) above were assigned the following values:

u = 1m/sec; $y = [1/2Cy^2 d^{2-n}]$ 1/2;

$\sigma z = [1/2Cz^2 d^{2-n}]$ 1/2; Cy = 0.45; Cz - 0.2 n = 0.4

h = 100 (Cold stack condition), 300M (Hot stack condition)

g. The whole body doses at the exclusion and low population zone distances due to direct gamma radiation from the fission products released into the reactor building were calculated and found to be less than 0.5 R/yr because of the external shield surrounding the containment vessel and, hence, the direct dosage from the contained fission products does not constitute a hazard.

h. As a result of the above design bases (g), the isotopes of iodine are controlling for the low population zone distance and population center distance. The low population zone distance results from integrating the effects of iodine 131 through 135. The population center distance equals the low population zone distance increased by a factor of one-third.

i. The source strength of each iodine isotope was calculated to be as follows:

Isotope	Exclusion Q (curies/megawatt)	Low Population Q (curies/megawatt)
I^{133}	.55	76.4
I^{132}	.68	1.40
I^{133}	1.19	18.5
I^{134}	.72	.91
I^{135}	1.04	5.4

Appendix "A-2"

These source terms combine the effects of fission yield under equilibrium conditions, radioactive decay in the reactor building, and the release rate from the reactor building, all integrated throughout the exposure time considered. In this example, pressure reduction with its associated reduction in leakage rate is assumed and, hence, this effect should be integrated into the source strength above. This integrated pressure correction reduces the dosage by the factor 0.5.

Further, if washdown can be assured by the use of internal or external sprays, the source strength may be reduced by this decontamination factor. No such reduction has been assumed in this specific example.

j. For the exclusion distance, doses from both direct gamma radiation and from iodine in the cloud escaping from the reactor building are calculated. Exclusion distances as required are established on the basis of the effect requiring the greater isolation.

k. In calculating the thyroid doses which result from exposure of an individual to an atmosphere containing concentrations of radioactive iodine, the following conversion factors were used to determine the dose received from breathing a concentration of one curie per cubic meter for one second:

Isotope	Dose (rem)
I^{131}	329
I^{132}	12.4
I^{133}	92.3
I^{134}	5.66
I^{135}	25.3

2. The data developed from the preceding calculation are summarized in Figure I, "Thyroid Dosage vs Distance."

Curve (A) is the dosage from a presumed ground level fission product release.

Curve (B) is the release quantity of Curve (A) modivied for a cold stack release

Curve (C) is the release quantity of Curve (A) modified for a hot stack release.

Curve (D) is the data of Curve (C) modified for a reduced leakage because of decreasing pressure within the containment vessel.

3. Summarizing the results given in Figure I, the following distances can be calculated for other than the reference power level.

a. Exclusion distance - In the case of a shielded containment vessel and stack discharge, the exclusion distance dosage criteria is not exceeded and, hence, this distance is zero.

Appendix "A-2"

b. Low population zone distance (miles)

Power Level (Thermal Mw)	No Stack	Cold Stack	Hot Stack
1500	3.3	2.7	0
1200	2.8	1.7	0
900	2.4	0	0
600	1.8	0	0
300	1.2	0	0
100	0.6	0	0

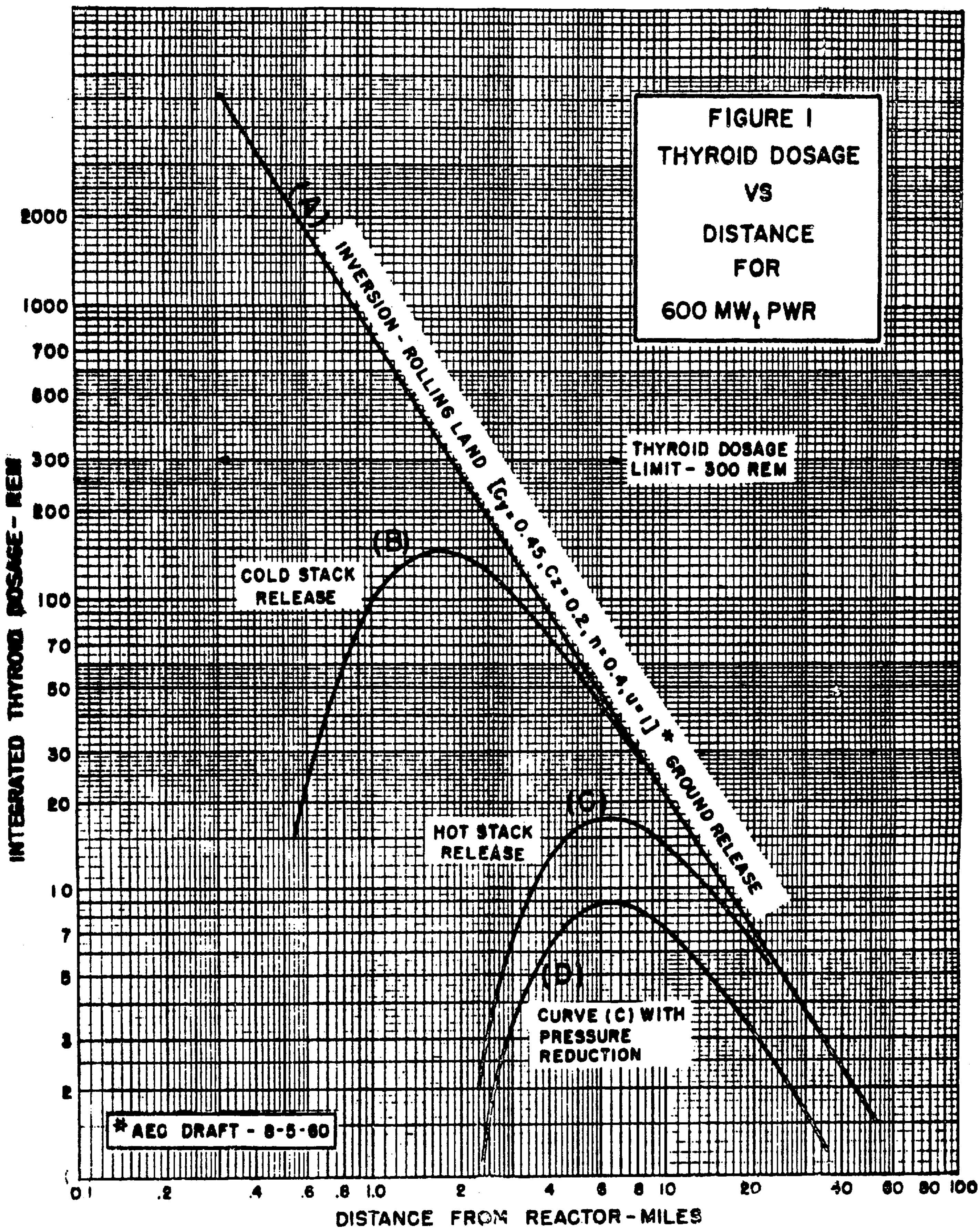


FIGURE I
THYROID DOSAGE
VS
DISTANCE
FOR
600 MW_t PWR
(A)
INVERSION - ROLLING LAND [C_y=0.45, C_z=0.2, n=0.4, u=1] * GROUND RELEASE
THYROID DOSAGE
LIMIT - 300 REM
(B)
COLD STACK
RELEASE
(C)
HOT STACK
RELEASE
(D)
CURVE (C) WITH
PRESSURE
REDUCTION
* AEC DRAFT - 8-5-60
INTEGRATED THYROID DOSAGE - REM
2000
1000
700
500
300
200
100
70
50
30
20
10
7
5
3
2
0.1
.2
.4
.6
.8
1.0
2
4
6
8
10
20
40
60
80
100
DISTANCE FROM REACTOR - MILES

APPENDIX "A-3"

Example of a Calculation of Reactor Siting Distances

1. The calculations in this Appendix are for a water cooled reactor with a vapor suppression or other type of containment in which the containment is shielded such that the gamma radiation from fission products inside the containment after an accident is very small and in which all fission products inside the containment after an accident is very small and in which all fission products leaking from the containment are collected and discharged through a stack with an effective height of 200 feet. Additional calculations are made for the case where the gases leaking from the containment are collected and 95% of the iodine in the gases removed with filter or scrubber. The following assumptions were used:

   a. The fission product release to the atmosphere of the containment is 100% of the noble gases, 50 % of the halogens and 1% of the solids in the fission product inventory. This release is equal to 15.8% of the total radioactivity of the fission product inventory. Of the 50% of the halogens released, one-half is assumed to adsorb onto internal surfaces of the containment or adhere to internal components.

   b. The release of radioactivity from the containment to the environment through the stack occurs at a leak rate of 0.05% per day of the atmosphere within the containment and the leakage rate persists throughout the effective course of the accident which, for practical purposes, is until the iodine activity has decayed away.

   c. In calculating the doses which determine the distances, fission product decay in the usual pattern has been assumed to occur during the time fission products are contained within the reactor building. No decay was assumed during the transit time after release from the reactor building.

   d. No ground deposition of the radioactive materials that leak from the reactor building was assumed.

   e. For the atmospheric dispersion during the first two hours after the accident a strong inversion was assumed to exist since this condition gives the largest dosages at the furthest points from the discharge stack. The stability parameter for the inversion was assumed to be $n = 0.5$. It was assumed that the wind speed was 1.5 meters/sec. representative of the winds prevailing at least 80% of the time at the site. For evaluating the atmospheric dispersion for the entire course of the accident to the edge of the low population zone, parameters selected represent average weather conditions for the site, $n = 0.2$ and an average wind speed of 3 meters per second.

f. The atmospheric dispersion was evaluated, using the meteorological parameters noted in item e, by the correlations and equations given by R. L. Seale and J. C. Couchman in their report Predicting Atmospheric Dispersal of Fission Products from Basic Meteoroligical Measurements, FZM-2025, October 12, 1960.

g. The source strength of each iodine isotope was calculated to be as follows:

Isotope	Exclusion Q (curies/megawatt)	Low population Q (curies/megawatt)
I-131	0.28	38.2
I-132	0.34	0.7
I-133	0.60	9.3
I-134	0.36	0.46
I-135	0.52	2.7

These source terms combine the effects of fission yield under equilibrium conditions, radioactive decay in the containment, and the release rate from the containment, all integrated throughout the exposure time considered.

h. In calculating the thyroid doses which result from exposure of an individual to an atmosphere containing concentrations of radioactive iodine, the following conversion factors were used to determine the dose received from breathing a concentration of one curie per cubic meter for one second:

Isotope	Dose (rem)
I-131	329.0
I-132	12.4
I-133	92.3
I-134	5.66
I-135	25.3

i. It was assumed that the shielding around the containment was sufficient to reduce the gamma radiation from the fission products inside the containment to insignificant levels at the site boundary.

2. Using the assumptions noted above, the calculations showed that discharge through a stack with an effective stack height of 200 feet and the shielding around the containment reduced the dosages close to the plant such that no exclusion area is required. The dose to the thyroid was found to be controlling for the distance to the low populated zone. If the leakage from the containment is discharged with no scrubbing to remove iodine, the following distances are calculated:

Power Level (Thermal Megawatts)	Exclusion Distance miles	Low Population Zone miles
<925	0	0
1000	0	.21

continued on next page

Appendix "A-3"

Power Level (Thermal Megawatts)	Exclusion Distance miles	Low Population Zone miles
1100	0	.22
1200	0	.23
1300	0	.24
1400	0	.25
1500	0	.26

If a filter or scrubber is installed which removed 95% of the particulates and iodines leaking from the containment before discharge to the stack, it was found that there is no restriction on exclusion distance or low population zone distances for reactor power levels much greater than 1500 thermal megawatts.

APPENDIX "A-4"

Example of a Calculation of Reactor Siting Distances

1. The calculations of this appendix are a pressurized water type of reactor to be constructed in a narrow river valley. It is assumed that the containment vessel has a demonstrated leak rate of 0.1% per day of the volume of gas contained. No credit is assumed for elevation of the sphere above ground.

   The calculations of this appendix are based upon the following assumptions:

   a. The fission product release to the atmosphere of the reactor building is 100% of the noble gases, 50% of the halogens, and 1% of the solids in the fission product inventory. At distances outside the facility controlled area it is assumed that inhalation of iodine isotopes as aerosols presents the controlling biological hazard.

      Of the 50% of the halogens released, one-half is assumed to adsorb onto internal surfaces of the reactor building, or adhere to internal components, thus leaving 25% of the original core halogen inventory available for leakage.

   b. The release of radioactivity from the reactor building to the environment occurs at a leak rate of 0.1% per day of the atmosphere within the building and the leakage rate remains constant for one day. At the end of the first day, leakage was assumed to terminate as a result of the use of water spray to reduce the pressure in the reactor building.

   c. In calculating the doses which determine the distances, fission product decay in the usual pattern has been assumed to occur during the time fission products are contained within the reactor building. No decay was assumed during the transit time after release from the reactor building.

   d. No ground deposition of radioactive materials that leak from the reactor building was assumed.

   e. The atmospheric dispersion of material leaking from the reactor building was assumed to occur according to the following relationship:

$$x = \frac{Q}{\pi u \sigma_y \sigma_z}$$

      Where Q is the rate of release of radioactivity from the containment vessel, the ("source term") and is stated in units of curies integrated over the exposure period,

      x - is the atmospheric concentration of radioactivity at distance d from the reactor, in curies per meter^3, integrated over the exposure period, u - is wind velocity (meters/second),

σy and σz - are horizontal and vertical diffusion parameters, respectively.

f. Meteorological conditions of atmospheric dispersion were assumed to follow a two-stage cycle. From time = 0 to t = 6 hours, a severe inversion is assumed with minimum dispersion of leakage products. At t = 6 and continuing to t = 24, conditions were assumed to improve as a result of increased wind speed and resultant improved dispersion. Full credit is taken for isotopic decay of fission products remaining within the vapor container.

For the purposes of these calculations, the parameters used in the equation in section (e) above were assigned the following values:

	t = 0 to t = 6 hours	t = 6 hours to t = 24 hours
u	1 meter/sec	5.5 meter/sec
σy	$(\frac{1}{2}\ Cy^2 d^{2-n})^{\frac{1}{2}}$	$(\frac{1}{2}\ Cy^2 d^{2-n})^{\frac{1}{2}}$
σz	$(\frac{1}{2}\ Cz^2 d^{2-n})^{\frac{1}{2}}$	$(\frac{1}{2}\ Cz^2 d^{2-n})^{\frac{1}{2}}$
Cy	0.4	0.4
Cz	0.07	0.3
n	0.5	0.2

g. Trial calculations have shown that whole body doses from direct radiation at the perimeter of a nominal facility controlled area (radius 1000 ft.) are not significant compared to the hazard resulting from inhalation of aerosols described above. Therefore, no separate calculation of this factor is given in this example.

h. As a result of the above design bases (a. and g.) the isotopes of iodine are controlling for the low population zone distance. The low population zone distance results from integrating the effects of iodine 131, 133 and 135. (No significant error results from omitting the isotopes 132 and 134.)

i. The source strength of each iodine isotope was calculated as the product of the curies available for leakage out of the vapor container at the beginning of each time interval, times the leakage rate, multiplied by a time averaging factor which accounts for the length of the discharge interval and the decay rate of the isotope.

	I^{131}	I^{133}	I^{135}
Leakage Rate at t = 0 Curies/Day/Megawatt	6.5	15.0	14.0
Time Average Factors (Days)			
6 hour release	0.25	0.23	0.19
18 hour release	0.74	0.56	0.34

Appendix "A-4"

Source strength of the Period t = 0 to t = 6 hours:

	Curies Per Megawatt
I-131	1.62
I-133	3.45
I-135	2.66

These source terms combine the effects of fission yield under equilibrium conditions, radioactive decay in the reactor building, and the release rate from the reactor building, all integrated throughout the exposure time considered.

j. Exclusion distances were calculated on the basis of airborne activity alone.

k. In calculating the thyroid doses which result from exposure of an individual to an atmosphere containing concentrations of radioactive iodine, the following conversion factors were used to determine the dose received from breathing a concentration of one curie per cubic meter for one second.

Isotope	Dose (rem)
I-131	329.0
I-132	12.4
I-133	92.3
I-134	5.66
I-135	25.3

2. The data developed from the preceding calculations are summarized in figure I "Exclusion and low Population Zone Distances."

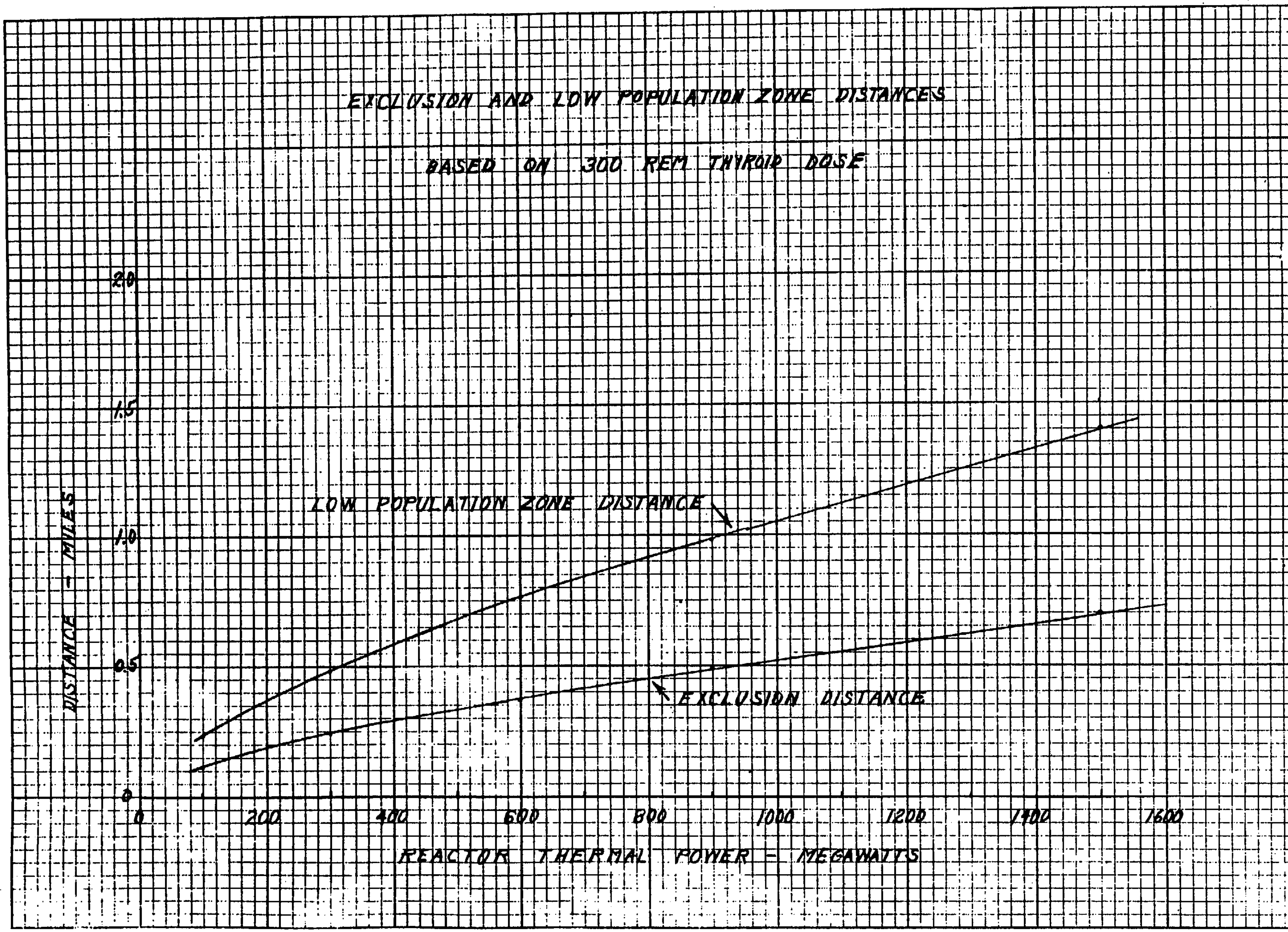
Calculations show that the dose received during the unstable periods is negligible compared to that received during inversion conditions.

3. Summarizing results given in Figures I and II, the exclusion and low population distances are as follows:

a. Exclusion Distance - Based on two hour exposure and a dose of 300 rem to the thyroid.

b. Low Population Zone Distance - Based on one cycle of 6 hours stable and 18 hours unstable air conditions, and a dose of 300 rem to the thyroid.

Reactor Thermal Power megawatts	Exclusion Distance miles	Low Population Zone Distance miles
1500	0.70	1.40
900	0.49	0.98
600	0.37	0.77
300	0.24	0.48
100	0.12	0.23


EXCLUSION AND LOW POPULATION ZONE DISTANCES
BASED ON 300 REM THYROID DOSE
LOW POPULATION ZONE DISTANCE
EXCLUSION DISTANCE
DISTANCE - MILES
2.0
1.5
1.0
0.5
0
0
200
400
600
800
1000
1200
1400
1600
REACTOR THERMAL POWER - MEGAWATTS