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SENSITIVITY AND UNCERTAINTY INVESTIGATIONS FOR HIROSHIMA DOSE ESTIMATES AND THE APPLICABILITY OF THE LITTLE BOY MOCKUP MEASUREMENTS

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DOSES WERE RECEIVED AT HIROSHIMA FROM SEVERAL RADIATION SOURCES

- Initial radiation (≤ 1 min)
  - Prompt neutrons and primary gammas from the device
  - Prompt secondary gammas produced in the environment (air, structure, ground)
  - Delayed neutrons and fission-product gammas from the fireball
- Residual radiation (≥ 1 min)
  - Neutron activation of ground and structures
  - Fission product fallout

A COMBINATION OF PROCEDURES ARE REQUIRED TO ESTIMATE THE DOSES RECEIVED FROM THESE SOURCES

- Radiation transport techniques (discrete ordinates, Monte Carlo) are used to determine the dose resulting from prompt neutrons and primary and secondary gammas
- Determination of doses from delayed neutrons and fission product gammas also require blast-hydrodynamic and fireball rise models
- Sources for residual radiation effects are determined by the initial radiation environment and the fission product fallout pattern

THE UNCERTAINTY IN THE RESULTING DOSE IS ESTIMATED BY EVALUATING THE UNCERTAINTIES DUE TO THE CALCULATIONAL PROCEDURE AND THE UNCERTAINTIES IN RELATED DATA

- Sensitivity studies are performed to identify the sensitivity of a particular calculational result to the input parameters or data required
- Uncertainty estimates are obtained for the parameters to which the result is sensitive
- Individual estimates for the various parameters are then combined with sensitivities to produce an uncertainty estimate for the result
- Overall uncertainty estimates for the received dose are determined by combining the uncertainties due to all partial results required by the dose calculation
- Covariances are established for related data such as nuclear test shots and the Hiroshima explosion
- These covariances are used together with sensitivities and bias factors to reduce the overall uncertainty estimates for the received dose

THE UNCERTAINTY IN FREE-IN-AIR RESPONSES CAN BE DETERMINED CONSIDERING SOURCES OF UNCERTAINTY ASSOCIATED WITH:

- Yield - magnitude (kt)
- Source
  - Number of leakage neutrons and gammas per kt
  - Energy, angular spectrum for leakage neutrons and gammas
- Primary transport
  - Air, ground composition
  - Burst height
  - Terrain effects
  - Cross sections, transport methods
  - Detector response functions
- Delayed radiation
  - Fission product composition
  - Fireball rise
  - Fission product dispersion

UNCERTAINTIES RELATED TO CALCULATION OF HOUSE SHIELDING EFFECTS ARE DIFFICULT TO ESTIMATE ACCURATELY

- Modeling
  - Detail of house model
  - Surrounding structures
  - House orientation to blast
- Transport
  - Cross sections
  - Transport methods

DETERMINING ABSORBED DOSE ALSO INVOLVES
UNCERTAINTIES ARISING FROM:

- Detail of body modeling
- Positions (sitting, standing, etc.)
- Location within house
- Orientation to blast
- Transport - cross sections and methods

THE MAIN SOURCES OF UNCERTAINTIES ARE:

- On-Site Activation
  - Sulfur activation
  - Iron activation (rebar, antennae, etc.)
  - Roof tile activation (∿tld)
  - Soil activation and fission product contamination

- Nuclear Test Shots
  - Free-in-air responses
  - Building shielding factors
  - Fission-product gamma tissue kerma
  - Residual radiation levels

- Integral Experiments (and Related Calculational Analysis)
  - LANL Little Boy mockup
  - Burlington Arsenal Weapons mockup
  - BRL air/ground measurements
  - TSF integral experiments
  - LLL pulsed sphere experiments

- Cross Section Data (Transport and Response Functions)
  - Evaluated uncertainties
  - Correlated covariance matrices
  - Recent measurements

A METHODOLOGY HAS BEEN DEVELOPED
FOR SYSTEMATICALLY OBTAINING BEST ESTIMATES
AND REDUCED UNCERTAINTIES FOR RESPONSES
(e.g. DOSES)

- This methodology consistently combines, via generalized least squares (or Bayesian) techniques, all apriori experimental and calculational results, including:
  - Calculated and measured values of all responses
  - Covariances of all integral experiments, including correlations between measurements from one experiment to another
  - Covariances of all differential parameters (e.g. cross-sections, fission spectra)
  - Estimated corrections (e.g. bias factors for group structure, geometry, quadratures) for methods approximations
  - Sensitivities of all integral parameters to all differential parameters (adjoint calculations used to determine sensitivities)

APPLICATION OF THIS METHODOLOGY YIELDS:

1. Best estimates for all final results
2. Reduced variances for these results
3. Best estimates for all input parameters
4. Reduced variances for these parameters
5. Best estimates for fluxes, adjoints, etc., for future use

- Methodology can be used on successive steps within the overall procedure, yielding (1) - (5) at each step.
- Methodology is convergent: more measurements → more universal results with smaller uncertainties.
- Methodology identifies inconsistent information → (large χ^2 and greater resulting uncertainty).

INITIAL APPLICATION OF THIS SENSITIVITY/UNCERTAINTY ANALYSIS METHODOLOGY WILL FOCUS ON AIR-OVER-GROUND CALCULATIONS

Major tasks are:

- Perform adjoint transport calculations
- Use adjoint calculations to obtain sensitivities
- Collapse cross-section covariance data to 37N26G group structure
- Collapse Monte Carlo error files for source to 37N26G group structure
- Incorporate these collapsed covariances and sensitivities to obtain data uncertainties

RELATING A GIVEN RESULT FROM AN INTEGRAL EXPERIMENT TO THE ACTUAL DOSE ESTIMATES FOR HIROSHIMA IS DONE THROUGH SENSITIVITIES AND COVARIENCE MATRICES

- Best estimates for all final results (i.e. doses and their uncertainties) depend on:
  - Sensitivities $\underline{S}$
  - Response - response covariances C_{rr}
  - Response - parameter covariances $C_{r\alpha}$
  - Parameter - parameter covariances $C_{\alpha\alpha}$
- Integral experiments are related both among themselves and final dose results through $\underline{S}$, C_{rr}, $C_{r\alpha}$, $C_{\alpha\alpha}$
- Relative "weights" attached to these relationships come through $\underline{S}$

BY EXPLICITLY SEPARATING SENSITIVITIES AND COVARIANCE MATRICES, THIS SENSITIVITY/UNCERTAINTY ANALYSIS METHODOLOGY PROVIDES FLEXIBILITY AND ECONOMY IN THE DETERMINATION OF UNCERTAINTY IN THE DOSE

- For example:
  - By partitioning matrices, partial contributions to final dose results can be calculated in any order, then combined efficiently
  - Improved data for C_{rr}, $C_{r\alpha}$, $C_{\alpha\alpha}$ can be used immediately and inexpensively to update final dose results
- This methodology is being successfully applied to the Pressure Vessel Radiation Damage problem and has resulted in:
  - Reduced overall uncertainty in fluence exposure
  - Improved best estimate (intermediate between calculation and measurements)

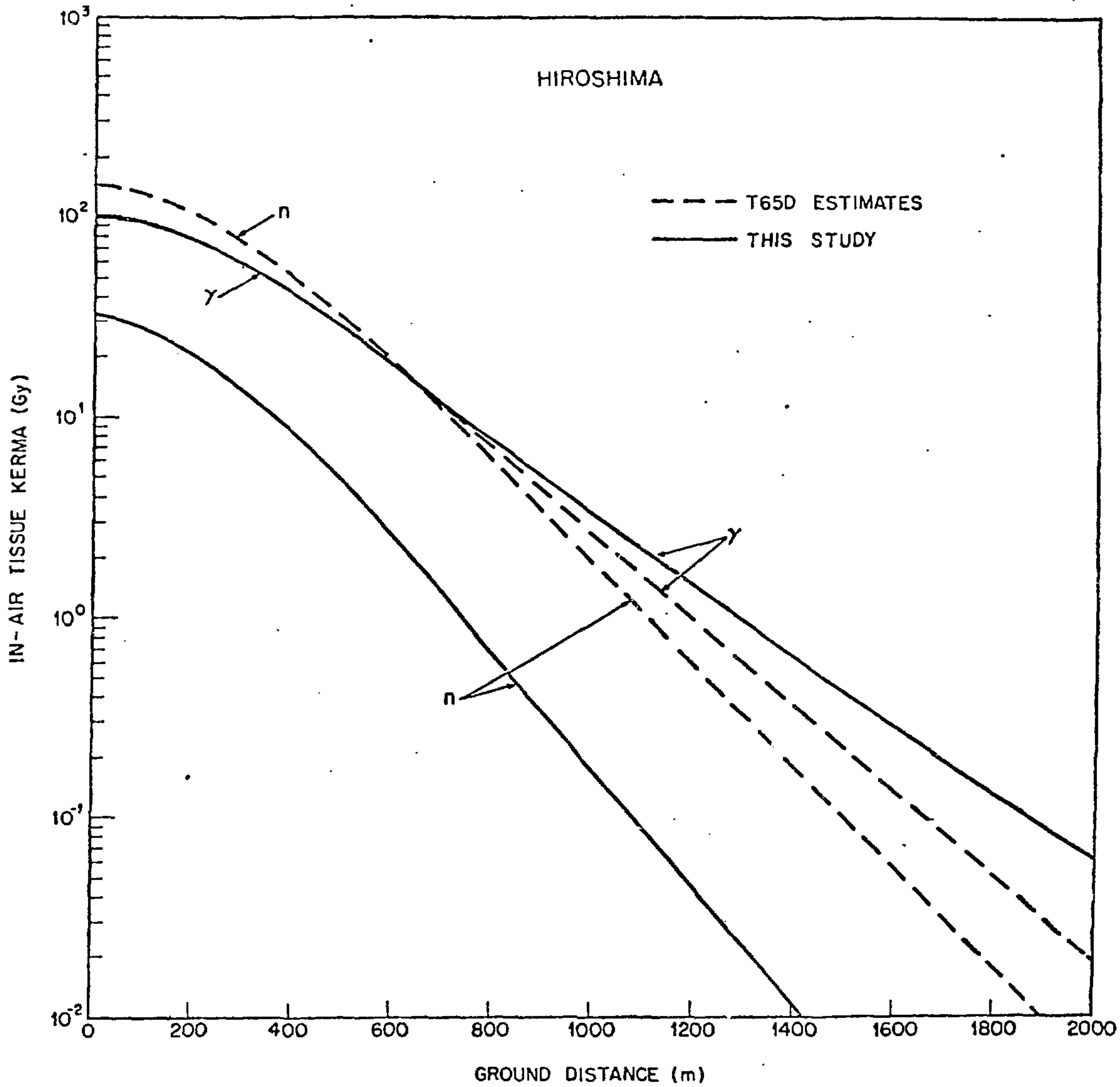
AS IT BECOMES AVAILABLE, ADDITIONAL
EXPERIMENTAL/CALCULATIONAL INFORMATION
WILL BE INCORPORATED IN THE
UNCERTAINTY ANALYSIS PROCEDURE

Recent Little Boy experiments/calculations can be used to reduce air/ground overall uncertainties by incorporating:

- Little Boy measurement uncertainties arising from counting, data reduction, instrument perturbation, background
- Calculational bias factors
- Calculational uncertainties due to cross sections

SOME PRELIMINARY SENSITIVITY AND UNCERTAINTY INFORMATION IS ALREADY AVAILABLE FOR THE HIROSHIMA DOSES

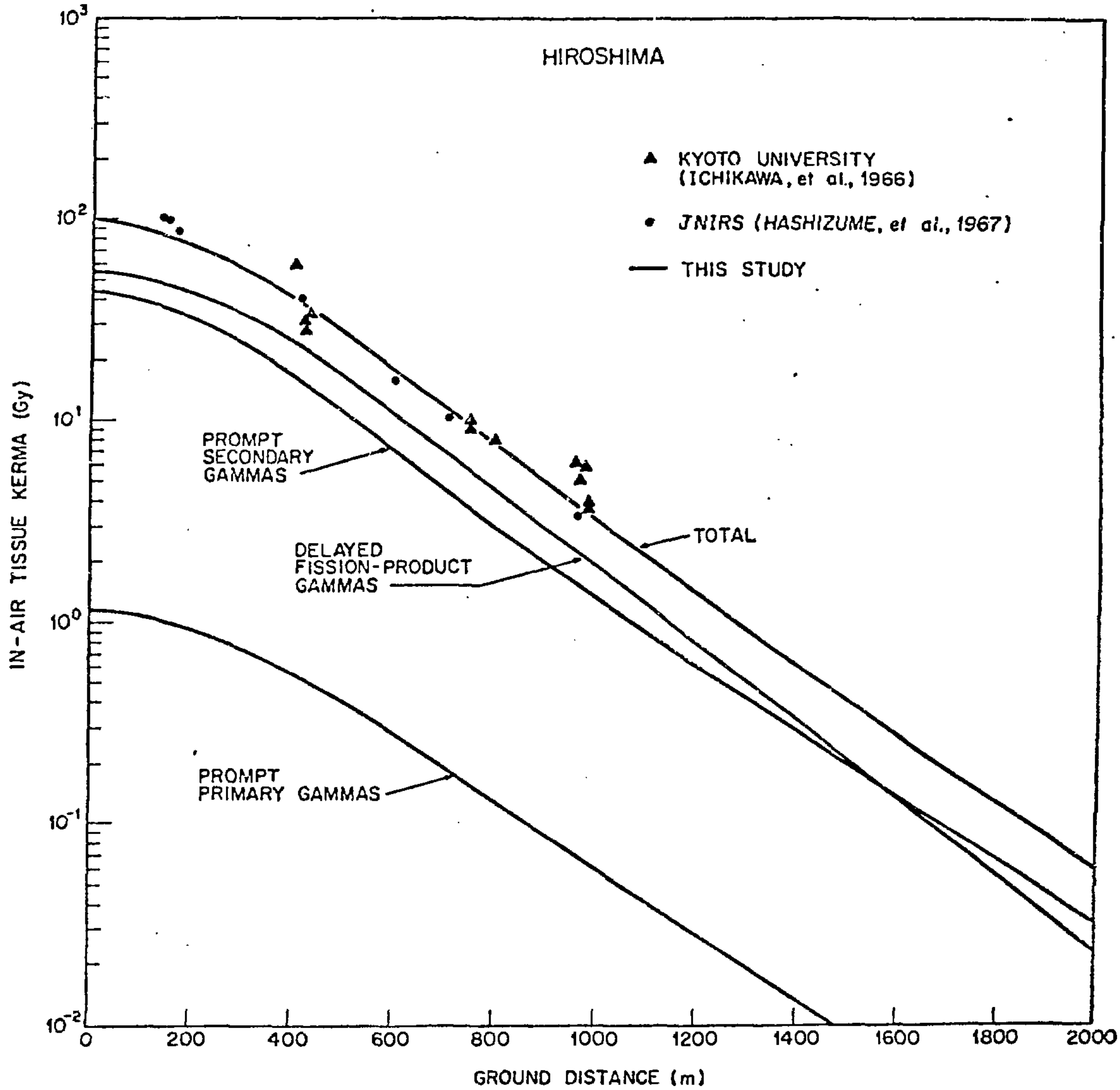
- Gamma contributions dominate the total free-in-air tissue kerma
- Delayed fission-product gammas and prompt secondary gammas both contribute significantly to the gamma free-in-air tissue kerma, but the prompt gammas from the device do not
- The free-in-air gamma tissue kerma shows reasonable agreement with roof tile activation measurement in the ground range dominated by delayed fission product gammas
- The free-in-air neutron tissue kerma is highly sensitive to the air moisture content, and secondary gamma production is also effected
- The sulfur activation data is not highly dependent on the detailed mockup of the insulator, but does show some dependence on the angular dependence of the source spectrum (East > West)
- More information is needed on the tissue kerma contribution of delayed neutrons and fission product gammas from U^{38} fission


HIROSHIMA
T65D ESTIMATES
THIS STUDY
n
γ
γ
n
IN-AIR TISSUE KERMA (Gy)
10³
10²
10¹
10⁰
10⁻¹
10⁻²
0
200
400
600
800
1000
1200
1400
1600
1800
2000
GROUND DISTANCE (m)

IMPLICATIONS OF THE LITTLE BOY MOCKUP MEASUREMENTS
FOR HIROSHIMA DOSE UNCERTAINTIES

- These measurements will impact the dose estimates by providing information on the yield and source
- First criticality
  - provides normalization point for yield estimation
  - directly effects dose estimation and all activation measurement comparisons
- Bonner ball measurements
  - total neutron leakage (cold), over all spectral information, (angular and energy), sulfur and rebar activation
- NE213 Measurements
  - high energy spectrum, sulfur activation
- Foil Activations
  - spectral information
- Gamma Dose (TLD and Roof Tile)
  - total gamma leakage (cold), roof tile activation

(16)


HIROSHIMA
KYOTO UNIVERSITY (ICHIKAWA, et al., 1966)
JNIRS (HASHIZUME, et al., 1967)
THIS STUDY
PROMPT SECONDARY GAMMAS
DELAYED FISSION-PRODUCT GAMMAS
TOTAL
PROMPT PRIMARY GAMMAS
IN-AIR TISSUE KERMA (Gy)
GROUND DISTANCE (m)
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
0
200
400
600
800
1000
1200
1400
1600
1800
2000

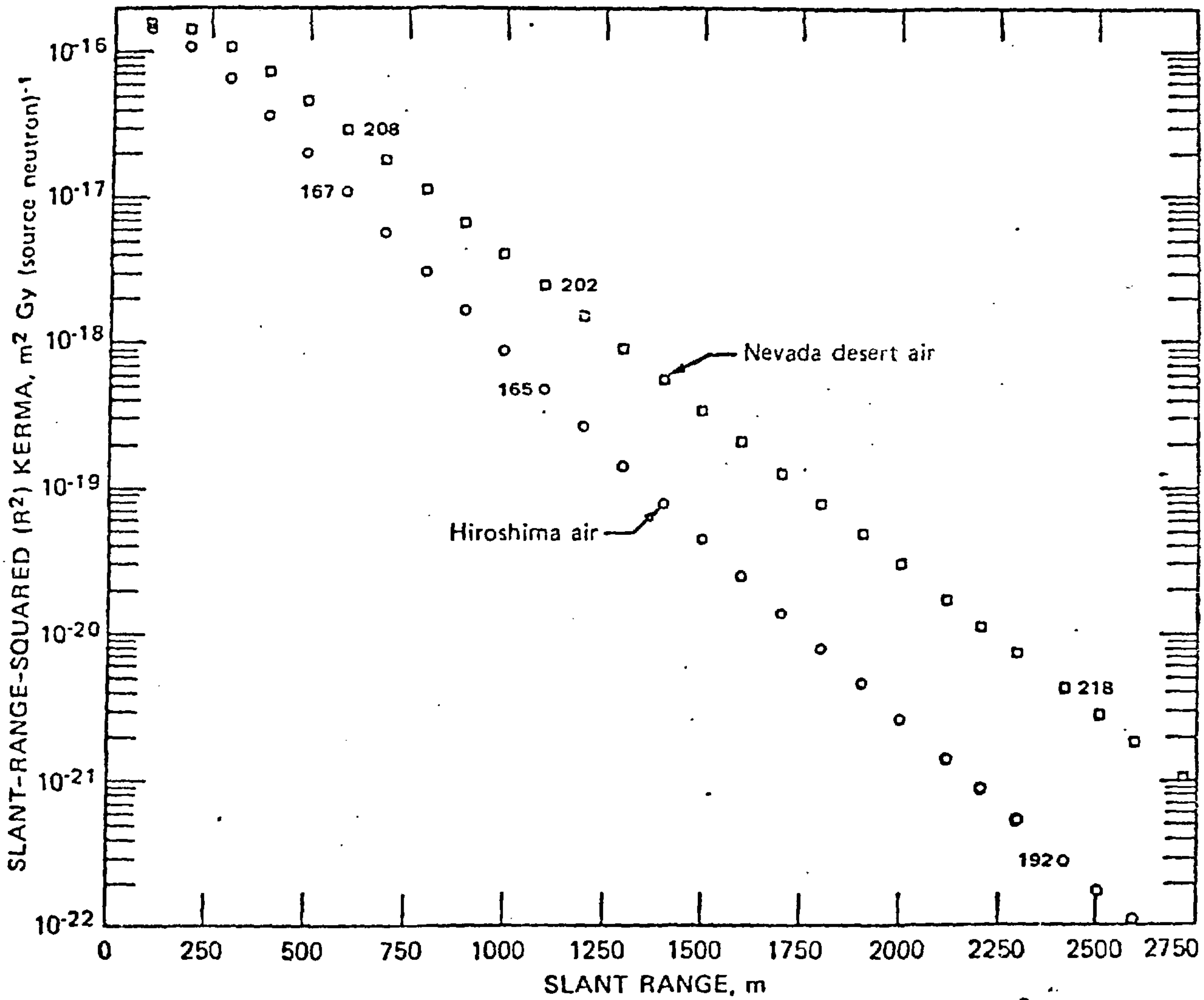
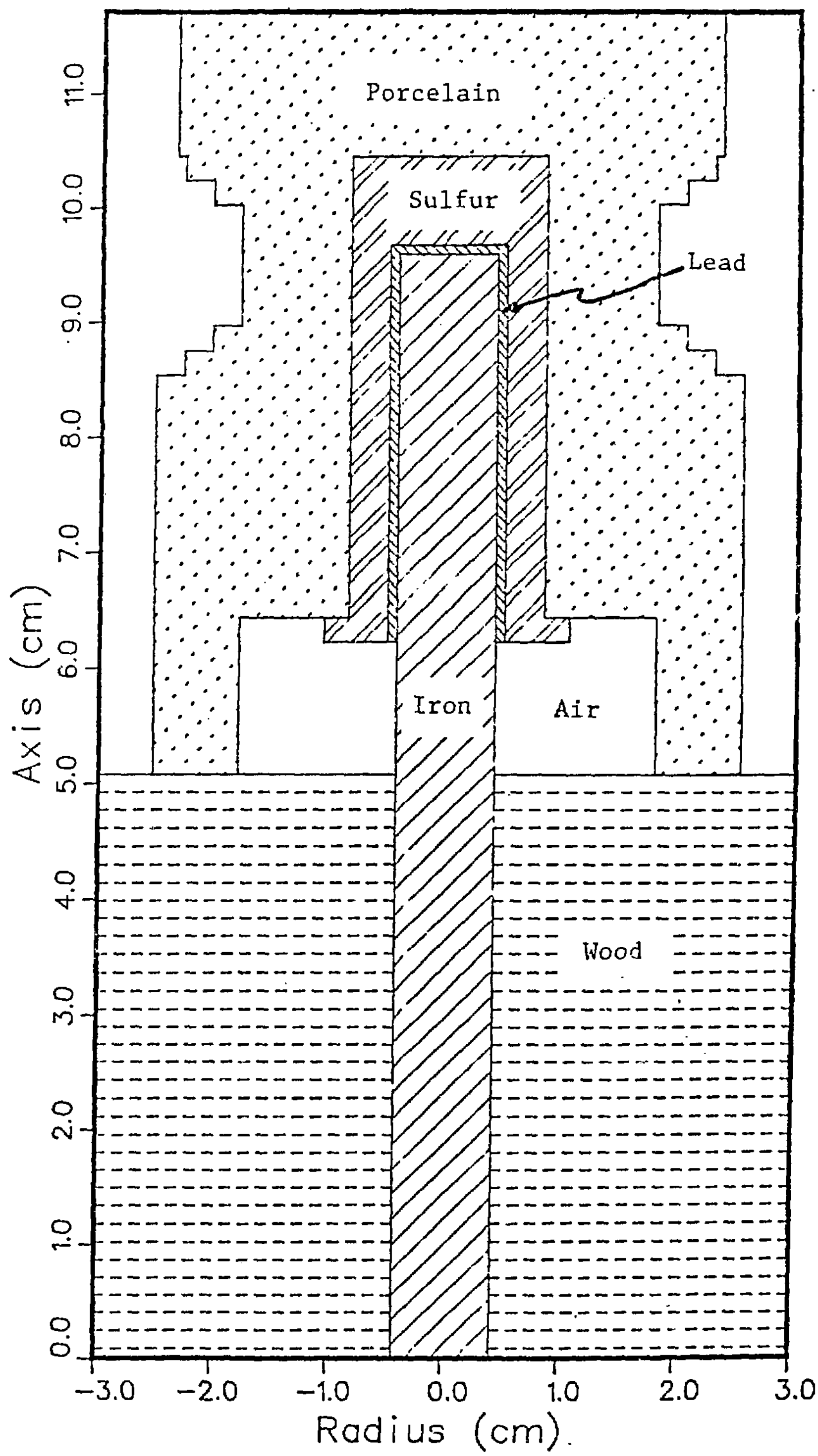


Fig. 17 Hiroshima slant-range-squared (R^2) neutron free-in-air tissue kerma in infinite air. The three-digit numbers next to some symbols represent the approximate relaxation lengths at those points.

Hiroshima Porcelain Insulator



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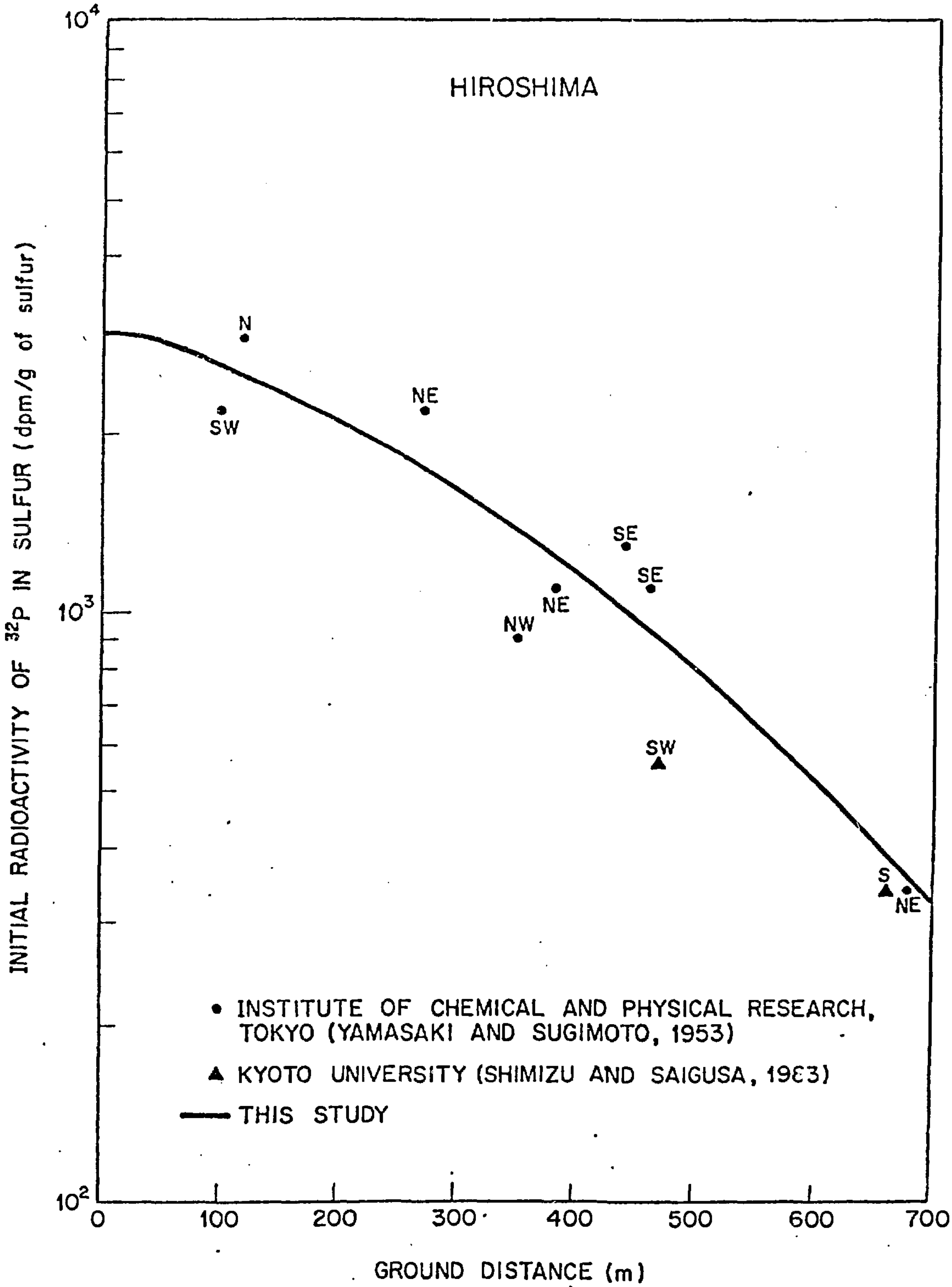

HIROSHIMA
INITIAL RADIOACTIVITY OF 32P IN SULFUR (dpm/g of sulfur)
GROUND DISTANCE (m)
10^4
10^3
10^2
0
100
200
300
400
500
600
700
N
SW
NE
SE
SE
NE
NW
SW
S
NE
• INSTITUTE OF CHEMICAL AND PHYSICAL RESEARCH, TOKYO (YAMASAKI AND SUGIMOTO, 1953)
▲ KYOTO UNIVERSITY (SHIMIZU AND SAIGUSA, 1963)
THIS STUDY