NUCLEAR CRITICALITY SAFETY MODELING OF AN LEU DEPOSIT

CONF-961103--19

M. J. Haire and K. R. Elam
Chemical Technology Division
P.O. Box 2008
Oak Ridge National Laboratory[1]
Oak Ridge, Tennessee 37831-6180

W. C. Jordan
Computational Physics and Engineering Division
Oak Ridge National Laboratory[1]
Oak Ridge, Tennessee 37831-6370

T. L. Dahl, Sr.
Decontamination and Decommissioning Program
Oak Ridge K-25 Site[2]
Oak Ridge, Tennessee 37831-7328

RECEIVED
OCT 23 1996
OSTI

Full-length paper for presentation at the
American Nuclear Society/European Nuclear Society
1996 International Conference and Embedded Topical Meetings
Washington, D.C.
November 10–15, 1996

[1]Managed by Lockheed Martin Energy Research Corp. under contract DE-AC05-96OR22464 for the U.S. Department of Energy.

[2]Managed by Lockheed Martin Energy Systems, Inc. under contract DE-AC05-84OR21400 for the U.S. Department of Energy.

NUCLEAR CRITICALITY SAFETY MODELING OF AN LEU DEPOSIT[1]

M. J. Haire and K. R. Elam
Chemical Technology Division

W. C. Jordan
Computational Physics and Engineering Division
Oak Ridge National Laboratory[2]
Oak Ridge, Tennessee 37831-6495

T. L. Dahl, Sr.
Environmental Restoration Program
Oak Ridge K-25 Site[3]
Oak Ridge, Tennessee 37831-7328

The construction of the Oak Ridge Gaseous Diffusion Plant (now known as the K-25 Site) began during World War II and eventually consisted of five major process buildings: K-25, K-27, K-29, K-31, and K-33. The plant took natural (0.711% ^{235}U) uranium as feed and processed it into both low-enriched uranium (LEU) and high-enriched uranium (HEU) with concentrations up to ~93% ^{235}U. The K-25 and K-27 buildings were shut down in 1964, but the rest of the plant produced LEU until 1985. During operation, inleakage of humid air into process piping and equipment caused reactions with gaseous uranium hexafluoride (UF_6) that produced nonvolatile uranyl fluoride (UO_2F_2) deposits. As part of shutdown, most of the uranium was evacuated as volatile UF_6. The UO_2F_2 deposits remained. The U.S. Department of Energy has initiated a program to improve nuclear criticality safety by removing the larger enriched uranium deposits (ref. 1.).

The largest ^{235}U deposit in the K-29 Building is of sufficient size and enrichment and in a geometry such that it cannot easily be demonstrated to be subcritical. This paper examines those random factors of safety that are keeping the deposit subcritical. Sensitivity calculations using factors that influence nuclear criticality

---

[1]The submitted manuscript has been authored by a contractor of the U.S. Government under contract DE-AC05-96OR22464. Accordingly, the U.S. government retains a paid-up, nonexclusive, irrevocable, worldwide license to publish or reproduce the published form of this contribution, prepare derivative works, distribute copies to the public, and perform publicly and display publicly, or allow others to do so, for U.S. Government purposes.

[2]Managed by Lockheed Martin Energy Research Corp. under contract DE-AC05-96OR22464, for the U.S. Department of Energy.

[3]Managed by Lockheed Martin Energy Systems, Inc. under contract DE-AC05-84OR21400 for the U.S. Department of Energy.

safety were made with SCALE's KENO V.a computer code (ref. 2). Factors varied in the sensitivity calculations were uranium enrichment (3 to 4%); neutron reflection (e.g., people and equipment coming into contact with the pipe); hydrogen content of the deposit (e.g., exposing the deposit to the moisture in air); and deposit configuration (annular, chord-shaped, or filling the pipe). These parameters, and measured deposit mass, are related to critical conditions (i.e., calculated $k_{eff} = 0.95$). Results of nuclear criticality safety analyses are shown in Fig. 1. Results of best estimate conditions are shown in Fig. 2.

The uranium deposit is located in Unit 2, Cell 7, in the 7BB2 valve and the 24-in.-diameter pipe leading to the B bypass line. This deposit has been measured by nondestructive assay (NDA) methods and was measured as 1,190 kg of uranium at 3.3% enrichment. This section of pipe has a 6-ft horizontal run with an 11-ft section that angles up at 60°. Because NDA measurements are estimated to have a 50% uncertainty for mass measurements and a 20% uncertainty for enrichment measurements, the deposit could contain as much as 1785 kg of uranium at about 4% enrichment. The angled section of pipe is partially filled; therefore, gravity could cause fissile material to shift within the pipe.

The UF_6 in an operating cascade is practically unmoderated in the absence of humid air inleakage. A range of moderation is possible when UO_2F_2 is formed. The neutron moderation level normally assumed in criticality evaluations for deposits exposed to air is H/U = 4 (ref. 3). A complicating factor is that uranium deposits can deliquesce—absorb excess moisture from air to become a solution. Therefore, calculations were performed for nearly three orders of magnitude of H/U ratios from an H/U = 0.8 to ratios of 50 and 500.

Figure 1 shows the neutron multiplication factor, k_{eff}, as a function of the uranium loading in the pipe, expressed as kg U per linear foot, for various configurations. The NDA estimate of the deposit mass corresponds to a uniformly distributed ~96 kg U/ft. If this deposit were to collapse and fill the pipe, its loading would be along the dotted line in the figure. The density, as determined by the H/U ratio (ref. 4), causes the linear loading to vary. Calculations (ref. 5) shown in Fig. 3 indicate that the nominal or full reflection assumption in the calculations has only a 2% effect on calculated k_{eff} when the deposit fills the pipe at an H/U = 4.0. Likewise, the effect of 3 or 4% enrichment has a relatively small 5% effect on calculated k_{eff} for a full pipe at an H/U = 4.0, as shown in Fig. 4. Chord-shaped deposits are more reactive than annular deposits because a chord has a greater mass per unit of surface area.

The sensitivity calculations described in this paper used a version of PC SCALE and a subset of these calculations were verified by running them on the validated mainframe computer code. The SCALE 4.1/KENO V.a and SCALE 27 group cross sections were validated for the IBM 3090™ (NK25B) mainframe at the Oak Ridge K-25 Site by comparing calculated predictions to 245 critical experiments (experimental $k_{eff} = 1.0$). A statistical analysis was performed and a lower k_{eff} acceptance criteria of $k_{eff} + 2\sigma < 0.9605$ was established (ref. 6). That is, a calculated $k_{eff} + 2\sigma < 0.9605$ may be considered safely subcritical. Because of the broad range of geometry and moderation (i.e., H/U values) considered in this study, an additional 1% margin was included for this work. Thus, a system with a calculated $k_{eff} + 2\ \sigma \geq 0.95$ is considered unsafe and may be critical.

It is concluded that at a normally assumed neutron moderation level of H/U = 4 used in criticality safety evaluations, credit must be taken for the distribution of uranium in the system to demonstrate subcriticality. If the distributed deposit were to collapse and collect in the lower portion of the process piping, the system could be critical if the actual H/U of the deposit exceeds about 2. The deposit will remain subcritical regardless of its distribution if the hydrogen content is below ~H/U = 1.0.

Those factors causing the existing deposit to remain subcritical, as is, are believed to be deposit configuration and hydrogen content. Although air-inleakage sources may be present, it is believed that the hydrogen content in the deposit is low because the Building K-29 process equipment has not been opened since plant enrichment operations ended.

REFERENCES

1. Haire, M. J., W. C. Jordan, J. C. Ingram, III, and T. L. Dahl, Sr., "Relative Risk of Nuclear Criticality from LEU and HEU Gaseous Diffusion Plant Deposits," *Proc. 1996 American Nuclear Society Annual Meeting*, June 16-20, 1996, Reno, Nevada, p. 203, American Nuclear Society, La Grange Park, Illinois (1996).

2. Oak Ridge National Laboratory, *SCALE, A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation*, NUREG/CR-0200, Rev. 4, Vols. I, II, and III (April 1995).

3. Russell, R. G., *Investigation of Hygroscopic Properties of Uranyl Fluoride*, KY/L-1669, Lockheed Martin Energy Systems, Paducah Gaseous Diffusion Plant, Paducah, Kentucky (November 1994).

4. Jordan, W. C. and J. C. Turner, *Estimated Critical Conditions for UO_2F_2-H_2O Systems in Fully Reflected Water Moderated Spherical Geometry*, ORNL/TM-12292, Lockheed Martin Energy Systems, Oak Ridge National Laboratory, (December 1992).

5. Haire, M. J., K. R. Elam, and W. C. Jordan, *Nuclear Criticality Analyses of a Uranium Deposit in the K-29 Building, K-25 Site, Oak Ridge, Tennessee*, K/ER-310, Lockheed Martin Energy Systems, K-25 Site, (June 1996).

6. Lee, B. L., Jr. and D. M. D'Aquila, *Validation of Nuclear Criticality Safety Software and 27 Energy Group ENDF/B-IV Cross Section*, POEF-T-3636, Rev. 1, Lockheed Martin Energy Systems, Portsmouth Gaseous Diffusion Plant, Portsmouth, Ohio, January 1996.

ORNL DWG 96C-188

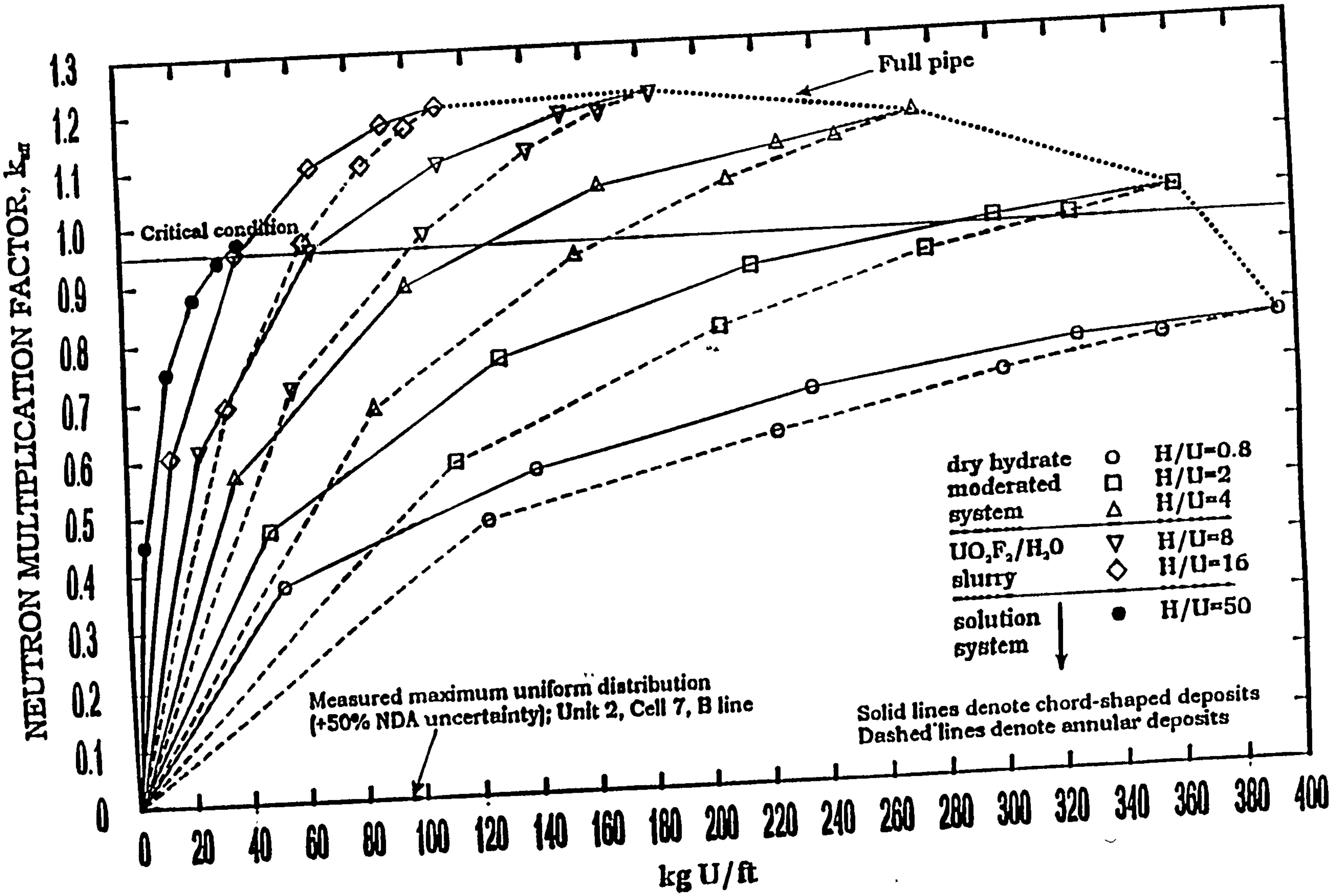

Fig. 1. Calculated k_{eff} of UO_2F_2 deposit in K-29 Building (4% enrichment, 24-in.-diameter pipe, full 12-in. water reflection)

ORNL DWG 96C-186

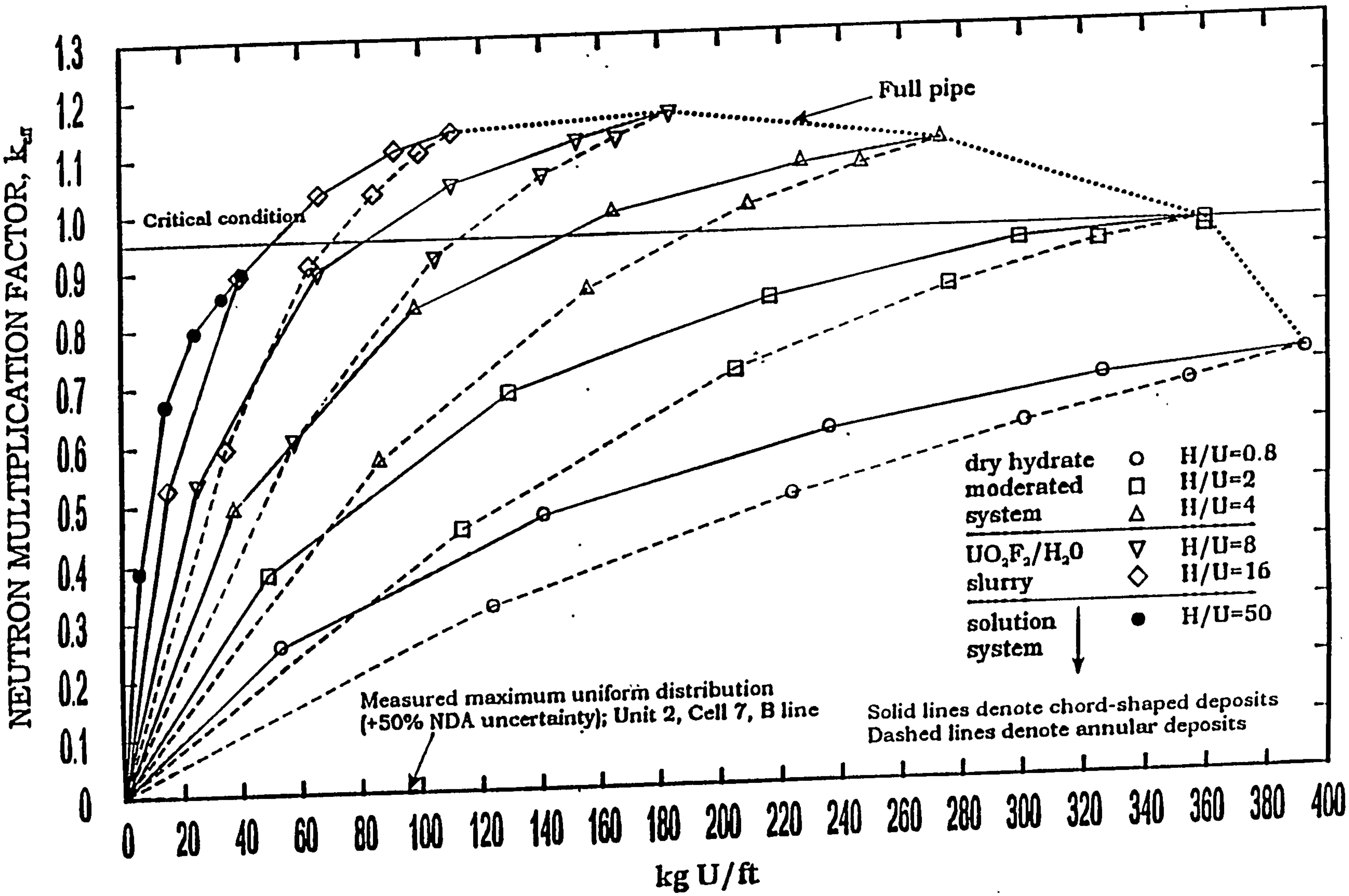

Fig. 2. Calculated k_{eff} of UO_2F_2 deposit in K-29 Building (3.3% enrichment, 24-in.-diameter pipe, nominal 1-in. water reflection).

ORNL DWG 96C-192

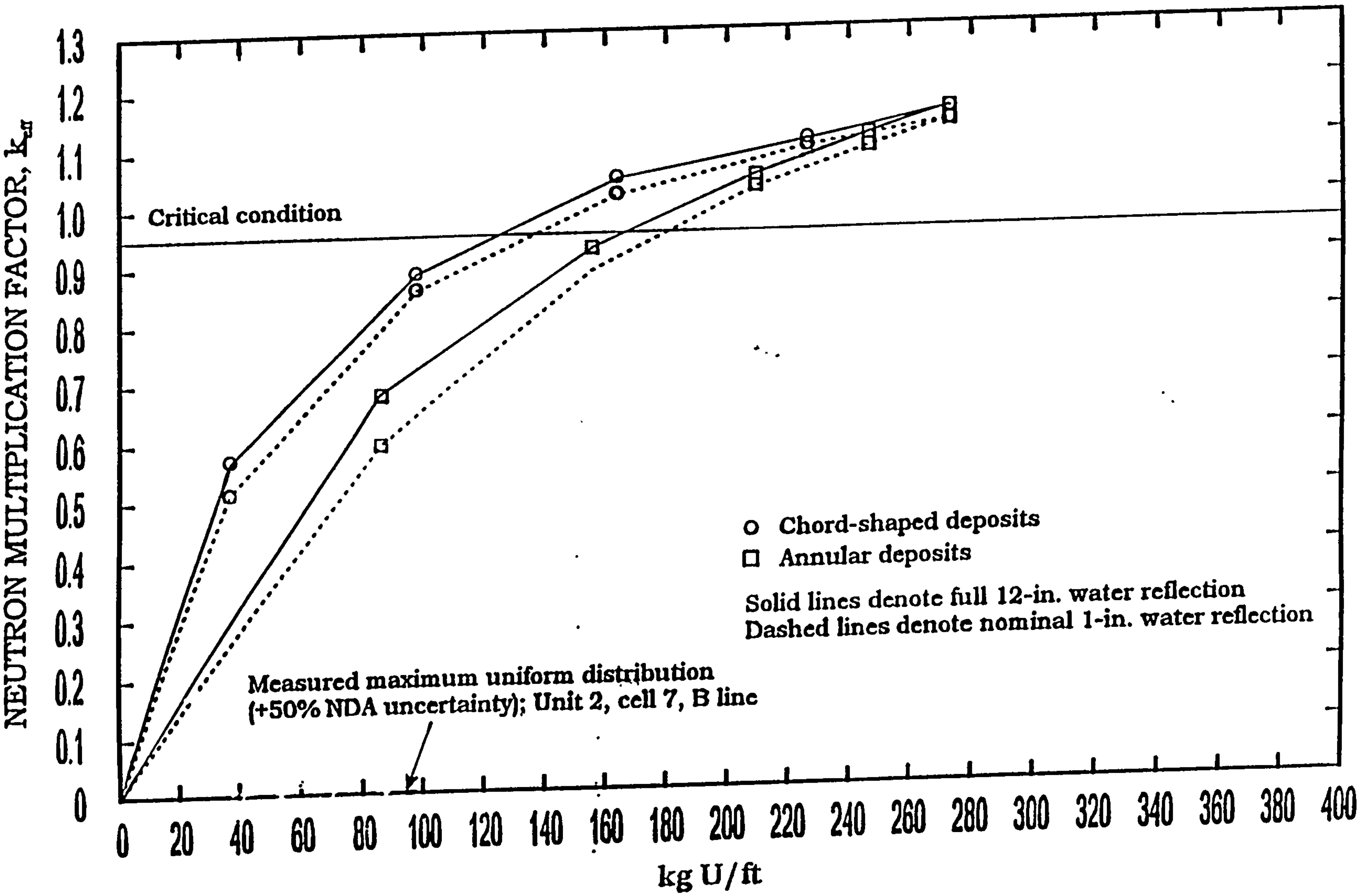

Fig. 3. Full or nominal reflection assumption has a relatively small effect (4% enrichment, 24-in.-diameter pipe, H/U = 4).

ORNL DWG 96C-191

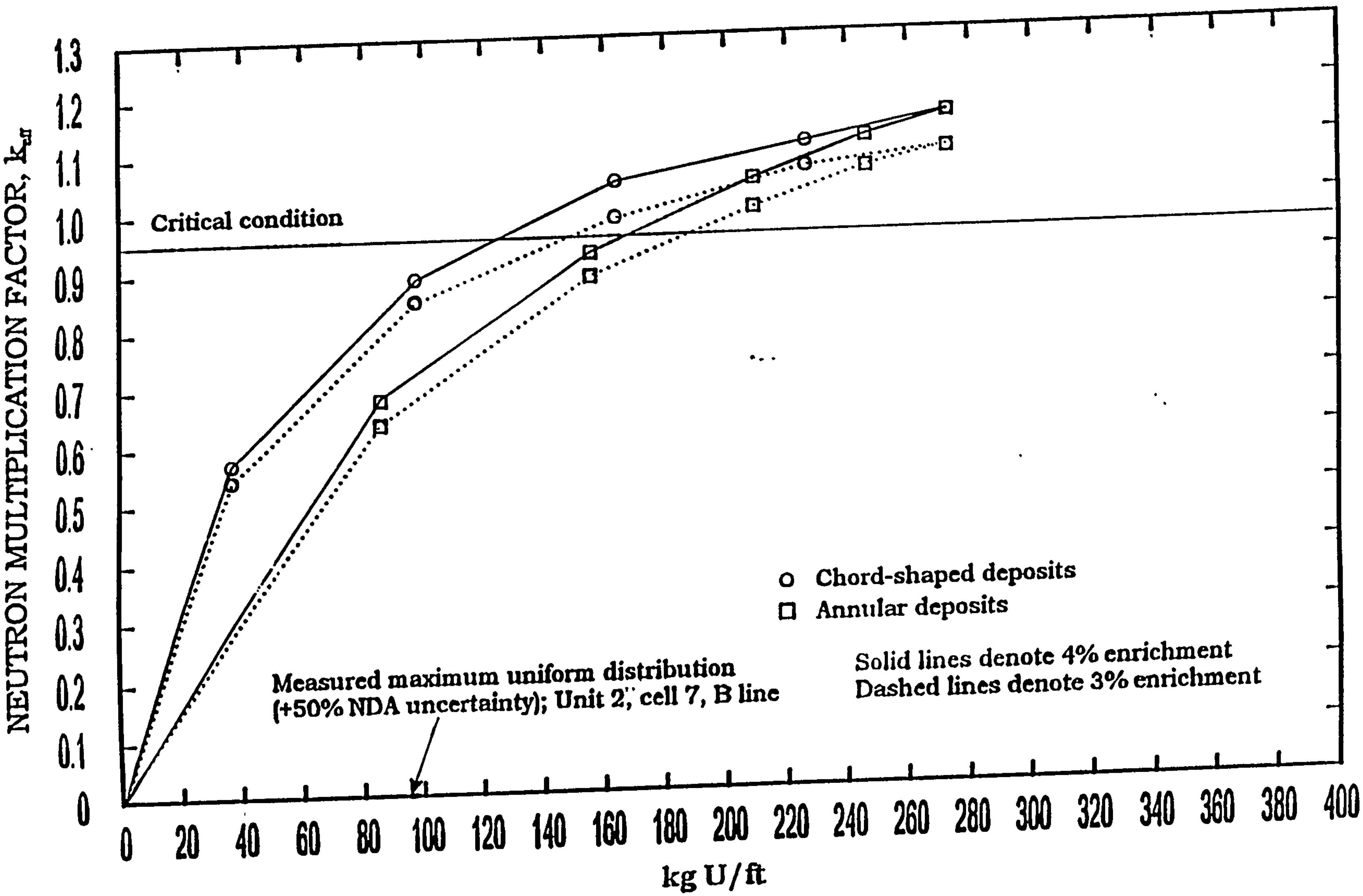

Fig. 4. 4 or 3% enrichment has a relatively small effect (full 12-in. reflection, 24-in.-diameter pipe, H/U = 4).