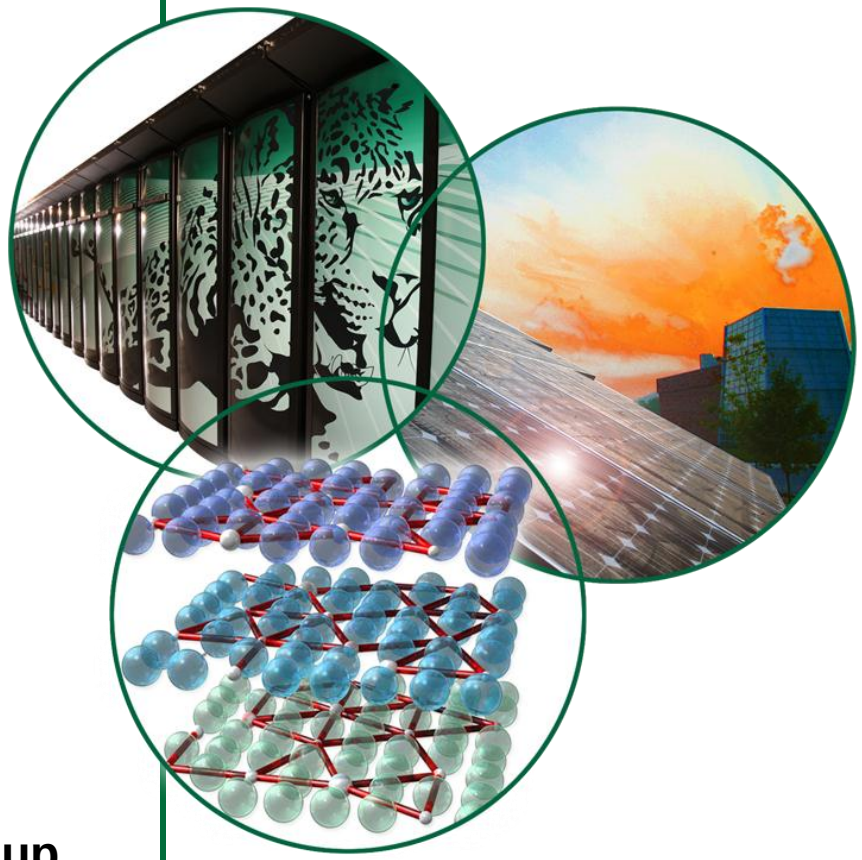
Estimation of Radiation Fields in PWR Biological Shield for Assessing Radiation Effects on Concrete



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U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
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Outlay

- Introduction
- Cavity dosimetry results available
- Calculations of neutron and gamma field
- Final comments

Introduction

- To assess the radiation effects on concrete in the biological shield neutron and gamma flux/fluence need to be determined
- Approximate but quick assessment is possible if cavity dosimetry results are available
- If cavity dosimetry is not available or if initial estimates indicate the need for more in-depth analysis, complete transport calculation needs to be performed

Cavity Dosimetry

Cavity dosimetry experiments:

- Dosimeters are irradiated in the cavity between the pressure vessel and biological shield
- There is practically no attenuation of the neutron flux through the reactor cavity
- Neutron flux determined from cavity dosimetry experiments provides reliable estimate of the flux impinging on the inner surface of the concrete shield
- Allow quick estimate to determine the plant position relative to the neutron fluence criterion for concrete and the need for further analyses
- Were performed on numerous plants

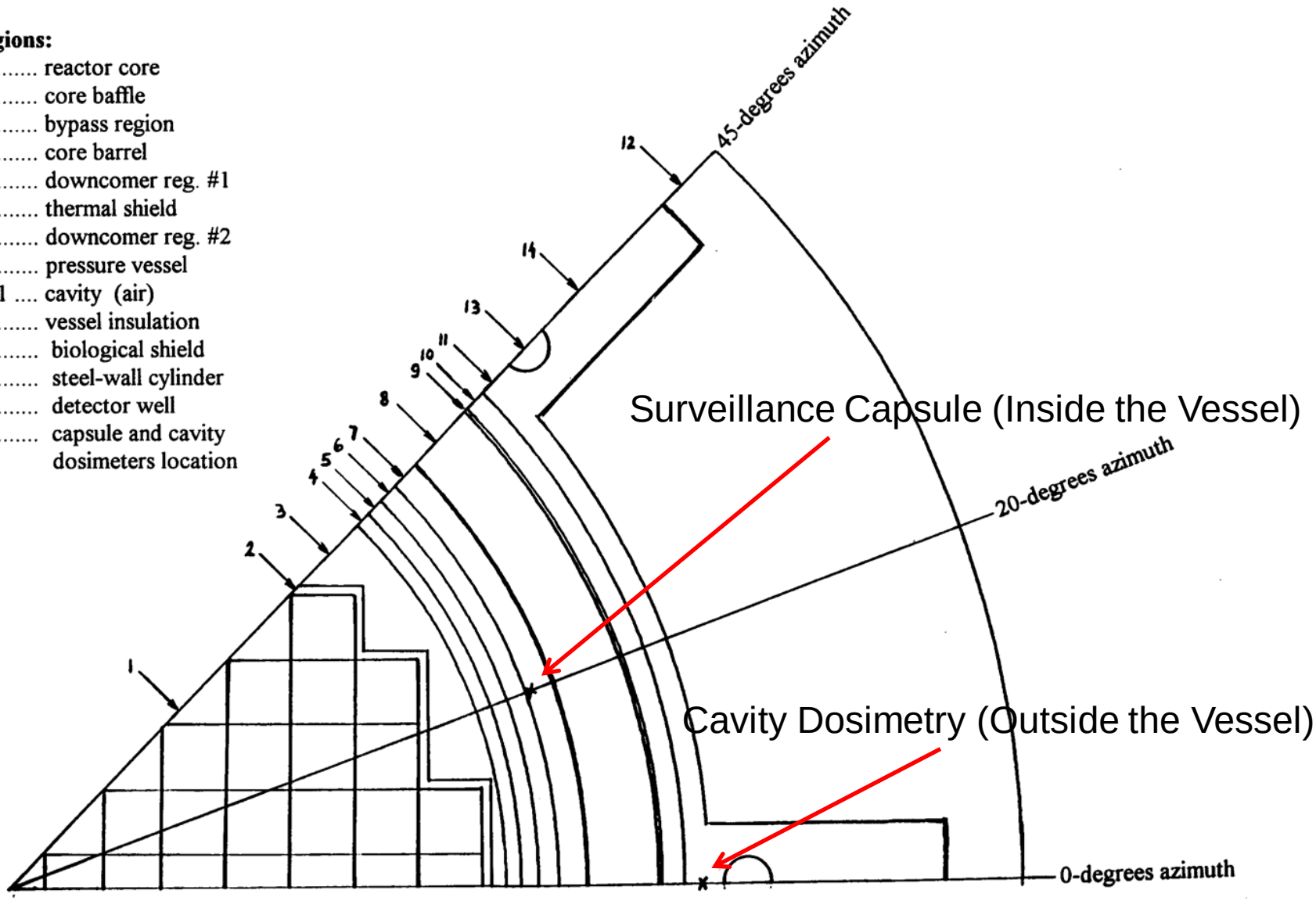
Two “Example” Plants

	TYPE	Thermal Power	PV Thickness	Thickness of Reactor Cavity	Inner Radius of Biological Shield
Plant A	3-loop PWR (W)	2300 MW	24.17 cm (9.5 “)	17.1 cm (6.7”)	238.76 cm (7’ 10’’)
Plant B	2-loop PWR (W)	1876 MW	16.84 cm (6.6”)	16 cm (6.3”)	200.6 cm (6’ 7”)

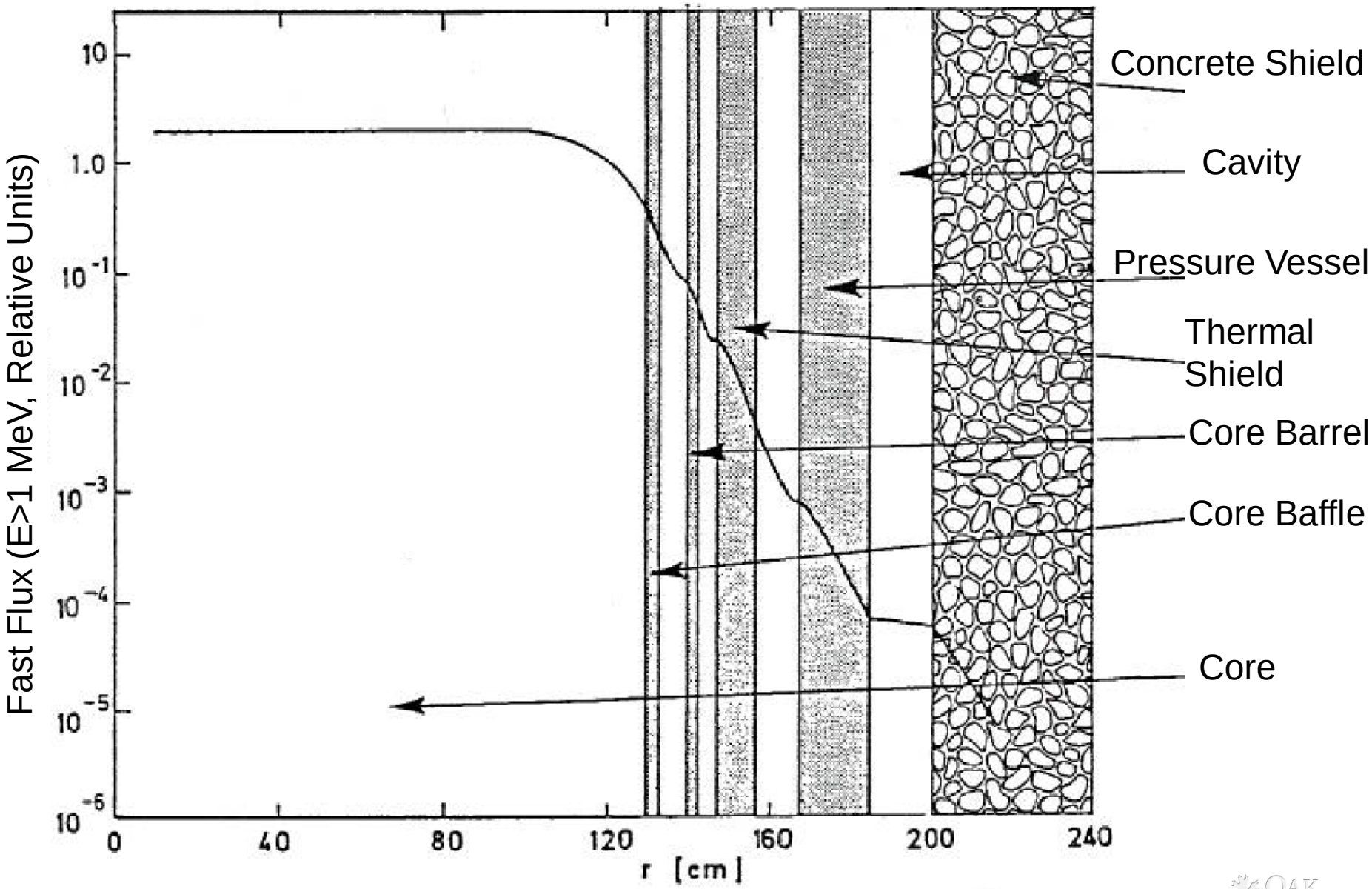
Both plants are still in operation.

Horizontal Section Through Plant A (Schematic)

Regions:
1 ..... reactor core
2 ..... core baffle
3 ..... bypass region
4 ..... core barrel
5 ..... downcomer reg. #1
6 ..... thermal shield
7 ..... downcomer reg. #2
8 ..... pressure vessel
9,11 .... cavity (air)
10 ..... vessel insulation
12 ..... biological shield
13 ..... steel-wall cylinder
14 ..... detector well
x ..... capsule and cavity dosimeters location



Plant B Vertical Section and Fast Flux Att.



Two "Example" Plants: Neutron Flux in the Cavity

		Integral Neutron Flux (cm^{-2} s^{-1})	Fast (E > 1MeV) Neutron Flux (cm^{-2} s^{-1})	Ratio Fast / Integral
Plant A		1.94 E+10	7.73 E+8	0.04
Plant B		6.52 E+10	2.61 E+9	0.04
Ratio		3.4	3.4	
Time to Reach Fluence 1.0 E+19 cm^{-2} (ANSI/ANS)				
Plant A		16.4 y	410 y	
Plant B		4.9 y	121 y	
Time to Reach Fluence 1.0 E+20 cm^{-2} (AMSE Boiler and Pres. Vessel Code)				
Plant A		164 y		
Plant B		49 y		

The cavity fluxes given above are specific for the two plants considered and do not represent upper or lower bounds for the current US power plants.

Cavity Dosimetry: Discussion

Corrections will be needed to account for:

- Spatial variations:
  - cavity dosimeters may not be located at the azimuthal and vertical maximum of the flux.
- Cycle-to-cycle variations:
  - cavity dosimeters are typically irradiated for 1 fuel cycle. Cycle-to-cycle variations need to be taken into account, especially if fuel loading pattern is changed, power upgraded, or other changes are introduced.

Probably will give no data on gamma flux.

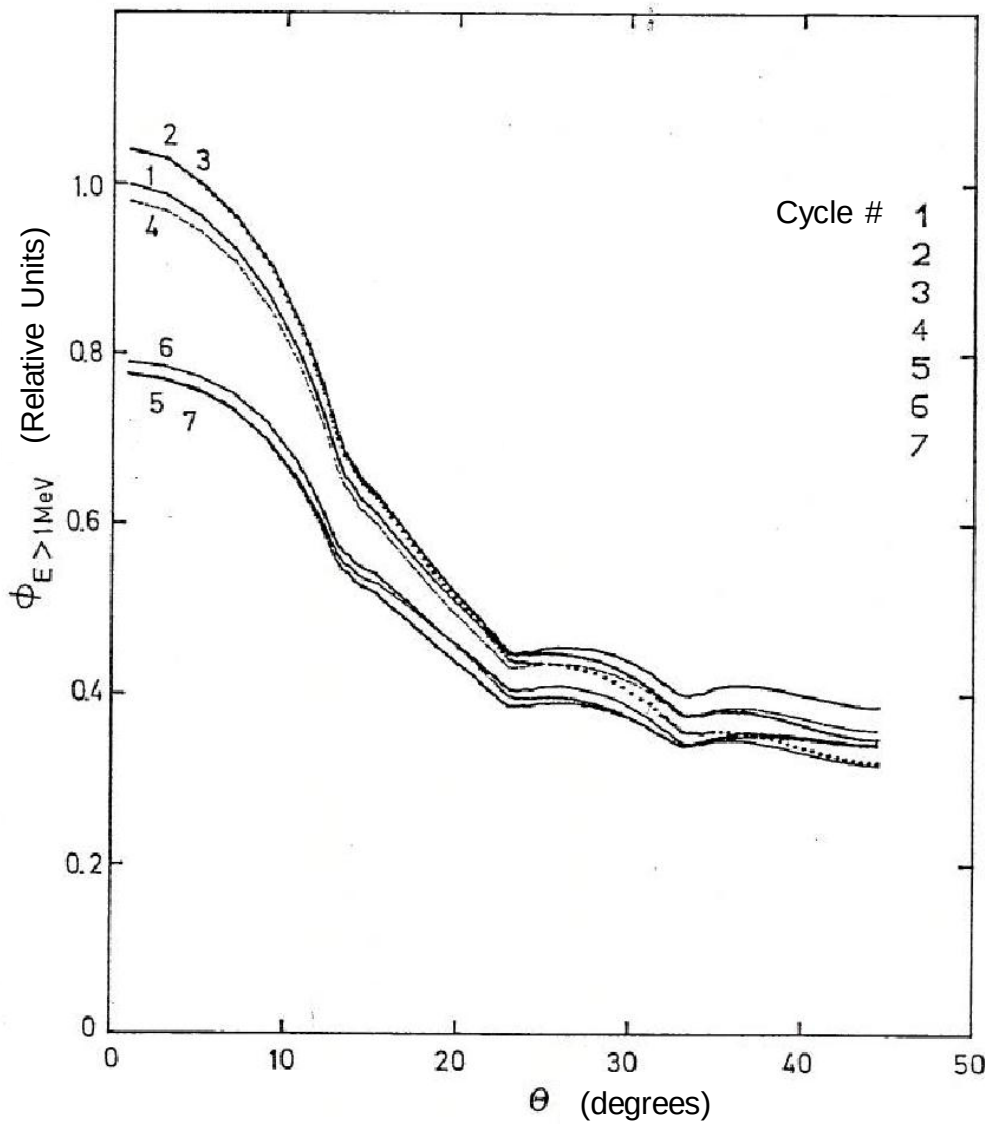
Flux profile inside the concrete shield is not obtained.

Availability of data may be a problem.

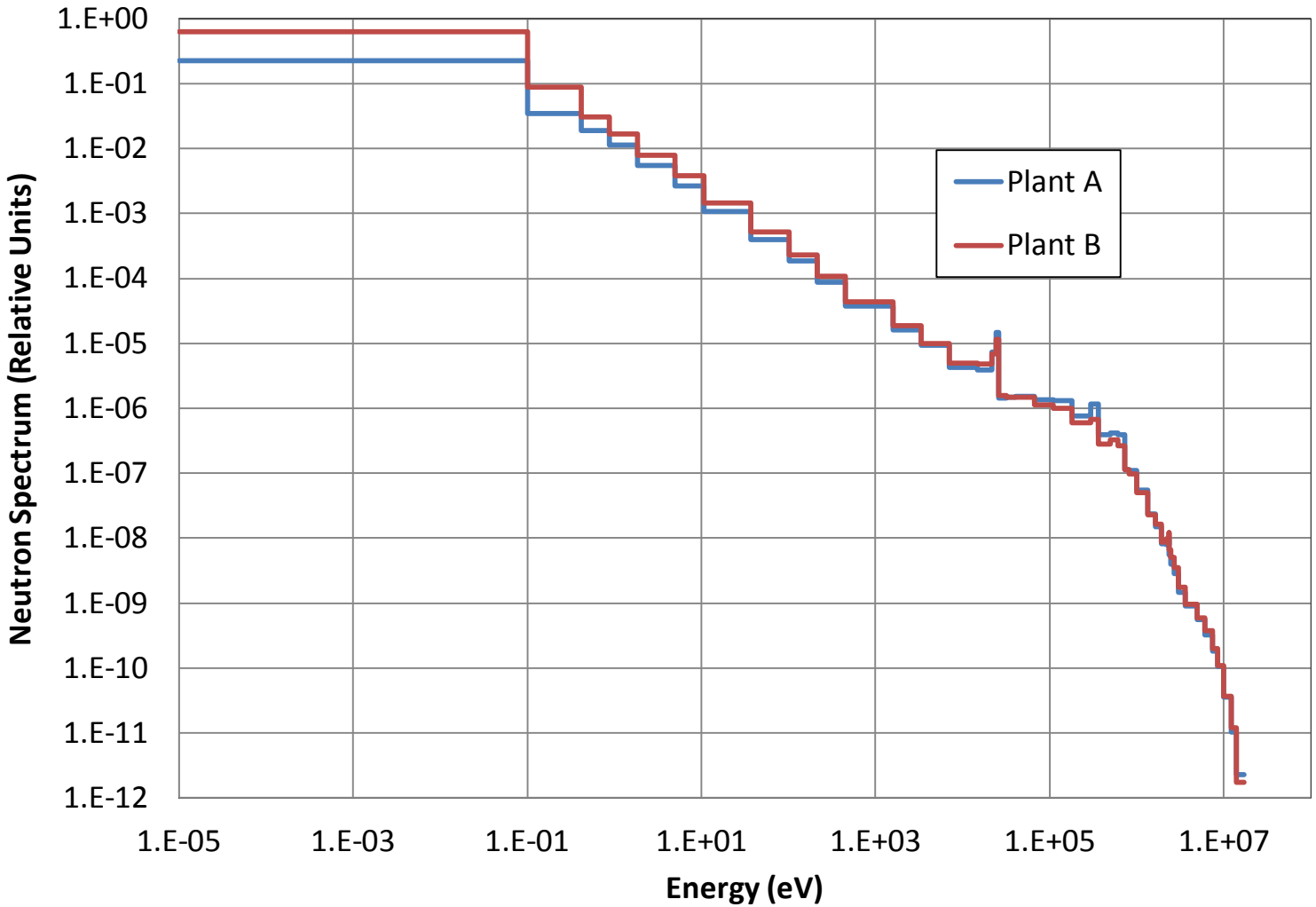
Azimuthal Fast Neutron Flux Distribution on the PV Inner Wall

Note the cycle-to-cycle variations.

The number next to the curve denotes the fuel cycle.



Comparison of Neutron Spectra in Cavity



Similar neutron spectra in cavity may allow simplified treatment of the attenuation in concrete shield.

Gamma Field in Concrete Shield

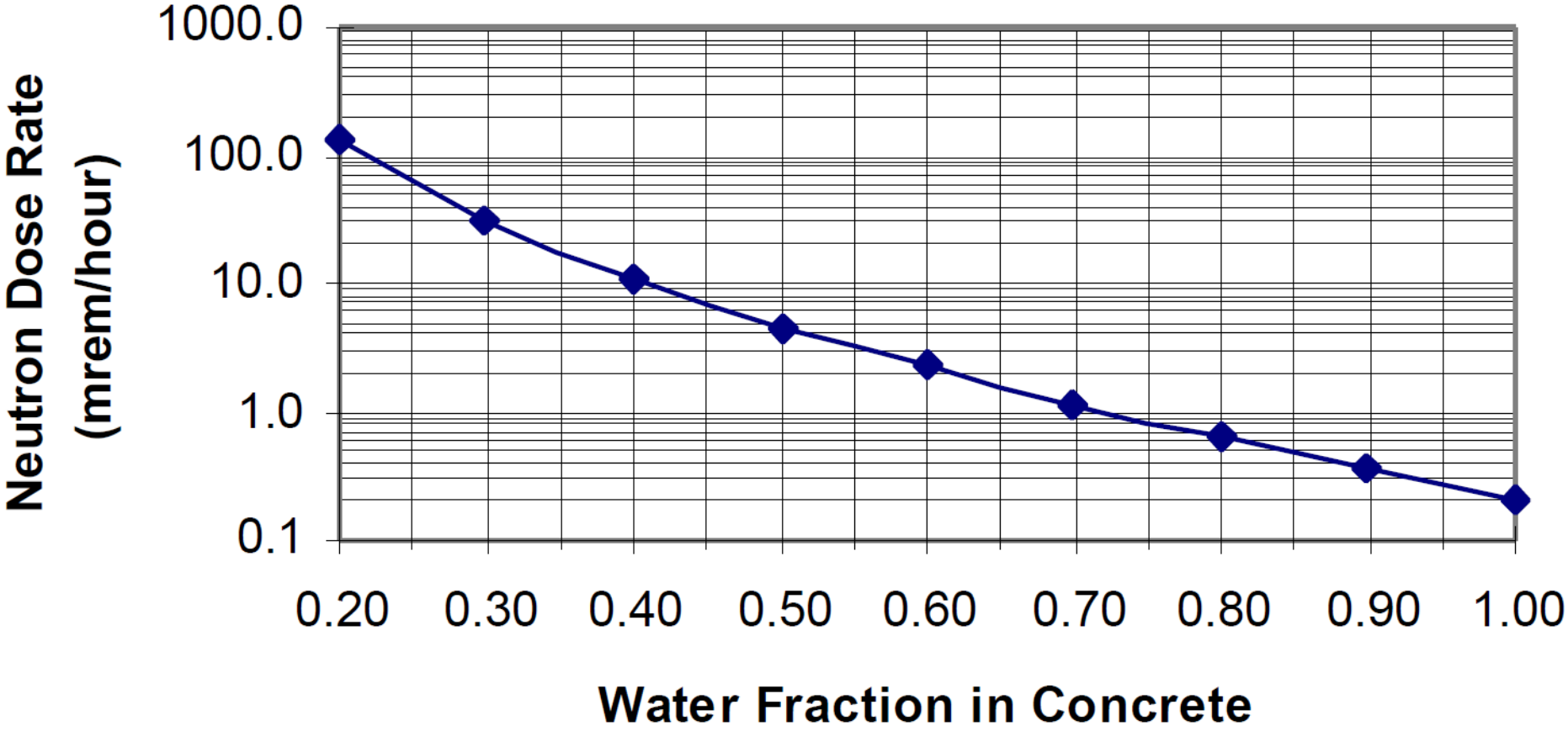
Gamma field in the concrete shield is generated primarily by neutron capture (n, γ) in concrete and in pressure vessel region close to the vessel outer surface

- **Gamma-ray flux is therefore to a large extent proportional to the neutron flux (maybe possible to develop simplified estimates)**
- **Gamma-rays generate heating in concrete and can result in considerably increased temperature in concrete shield close to the pressure vessel**
- **If temperature increase is large enough it may contribute to the degradation of concrete**

Transport Calculations of Neutron and Gamma Field

- Codes, cross sections and procedures that are used for pressure vessel flux calculations should be adequate
- Larger geometry models and longer computer cpu times will be needed, but this should not be a significant obstacle
- Core power distribution representative of the plant past and anticipated future operation should be used. (This may be time consuming to obtain if not available from the PV surveillance analyses.)
- The chemical composition and the water content of concrete needs to be know.

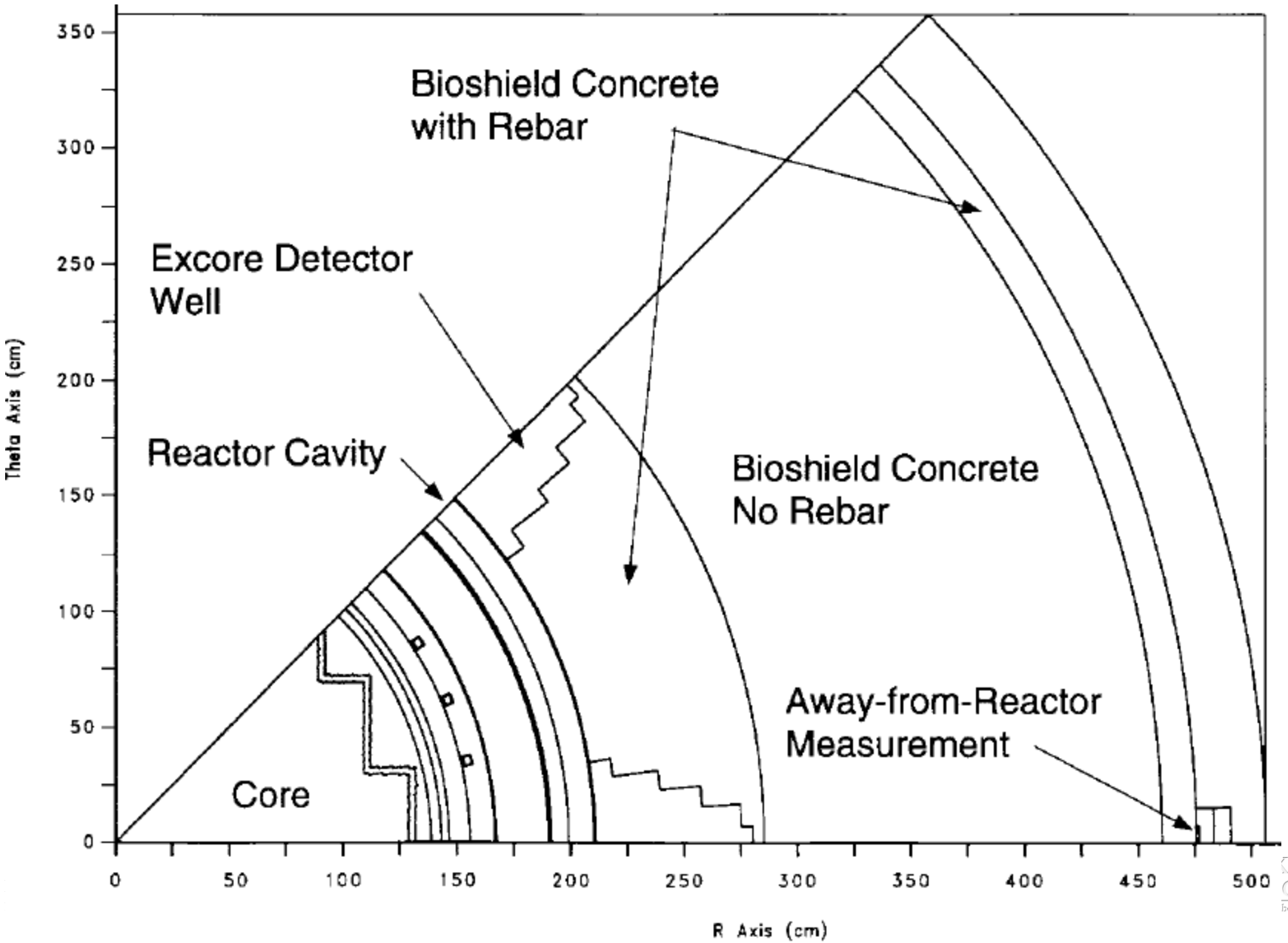
Neutron Dose Rate Outside the Biological Shield Versus Water Content



Neutron dose rate outside 2.65 m-thick concrete shield increases by a factor of 22 if water content drops by 50%.

From: Fero, Arnold H., "Use of SSTRs and a Multi-Component Shield Assembly to Measure Radiation Penetrating the Reactor Biological Shield in the Presence of Radiation Streaming from Other Sources," *Reactor Dosimetry, ASTM STP 1398*, 2000

Model For the Results on Previous Slide



Transport Calculations of Neutron and Gamma Field

- Direct calculations of neutron and gamma field in the concrete biological shield requires considerable effort

- Provide distributions throughout the shield of:
  - neutron and gamma fluxes
  - gamma-ray heating rate
  - allow calculation of concrete activation

Final Comments

- An approach to initial evaluation of the radiation field in concrete based on cavity dosimetry results may be applicable and should be considered
- Availability of cavity dosimetry results may pose a problem
- Full analysis based on transport calculations may be necessary if:
  - Cavity dosimetry results are not available
  - Plant is close to or exceeding fluence limits
- The allowable fluence limit for concrete needs to be carefully examined.

Additional Slides

Effects of Radiation on Concrete

The report by D. L. Fillmore: "Literature Review of the Effects of Radiation and Temperature on the Aging of Concrete," INEEL/EXT-04-02319, 2004

Concludes that:

- No effects of radiation were found for exposures less than 10^{10} neutron/cm^2 or 10^{10} Gy gamma for periods less than 50 years.
- Reductions in compressive and tensile strength and a marked increase in volume are reported for exposures greater than 10^{20} neutron/cm^2 or 10^{10} rads of gamma.
- There are conflicting reports of damage for doses in the middle ranges

Effect of Radiation on Concrete

- American National Standard Institute (ANSI) ANSI/ANS-6.4-1985: strength and modulus of elasticity are degraded if concrete is exposed to greater than 10^{19} n/cm^2 or to an integrated dose of gamma radiation exceeding 10^{10} rads.
- Section III, Division 2 of the ASME *Boiler and Pressure Vessel Code* gives a radiation exposure level allowable for concrete to be 1 x 10^{20} neutrons/cm^2.

Compressive Strength of Concrete Exposed to Neutron Radiation

Source: H Hilsdorf, J. Kropp, H. Kock, *The Effects of Nuclear Radiation on the Mechanical Properties of Concrete,* American Concrete Institute report SP-55-10, 1978; also in D. L. Fillmore, "Literature Review of the Effects of Radiation and Temperature on the Aging of Concrete," INEEL/EXT-04-02319, 2004

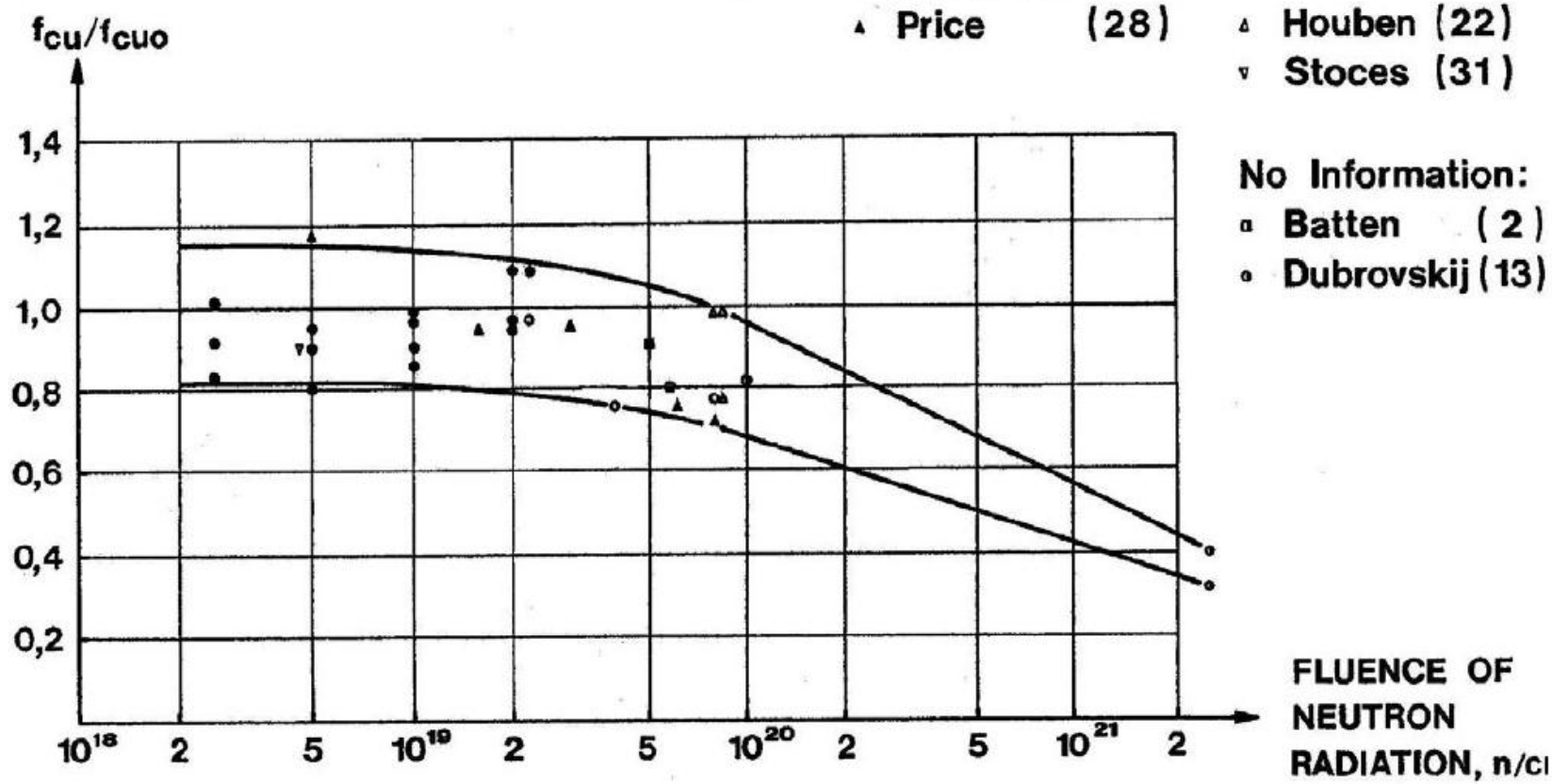
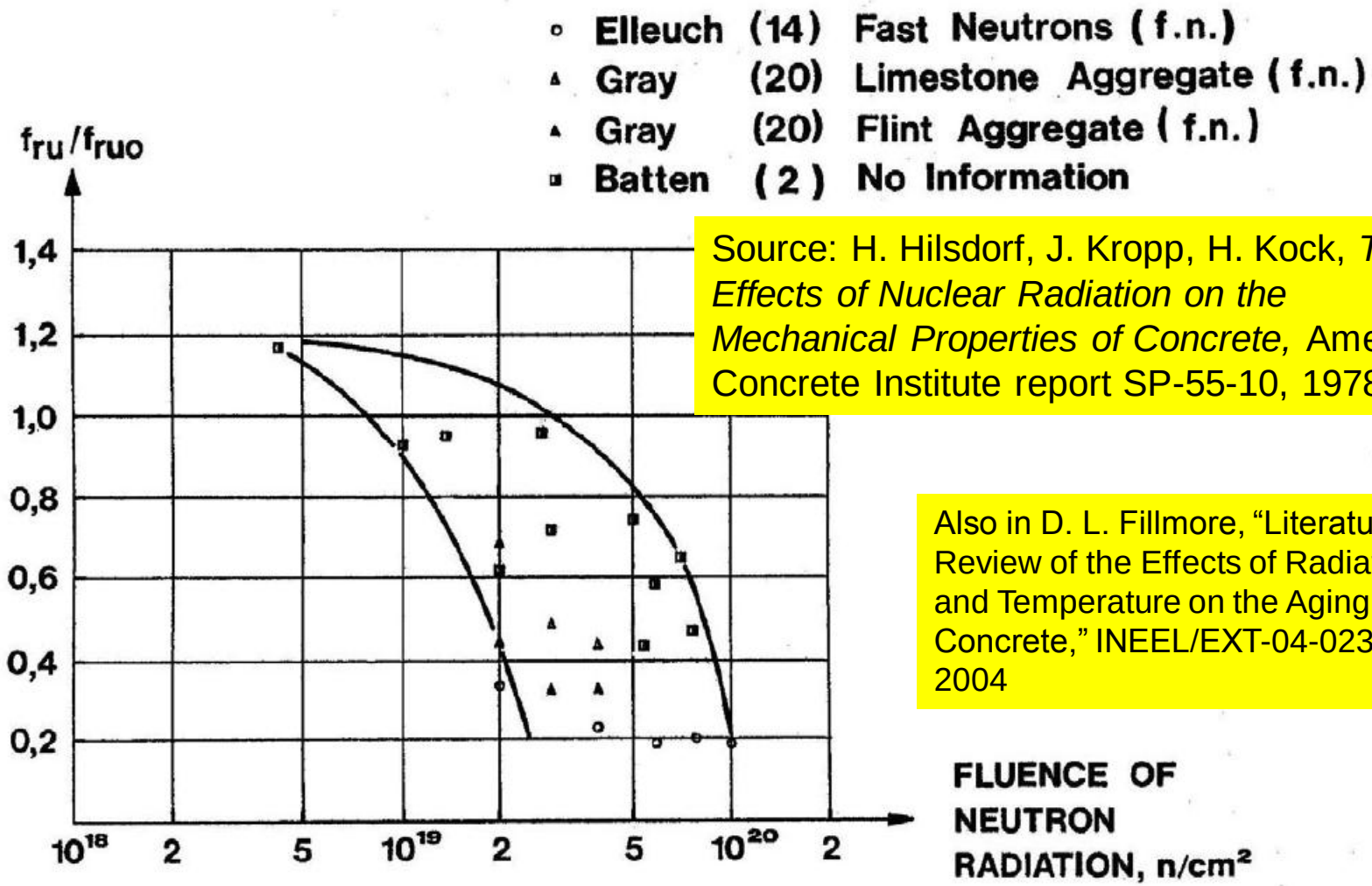


Figure 2. Compressive strength of concrete exposed to neutron radiation f_{cu} related to strength of untreated concrete f_{cuo}

Tensile Strength of Concrete Exposed to Neutron Radiation



Source: H. Hilsdorf, J. Kropp, H. Kock, *The Effects of Nuclear Radiation on the Mechanical Properties of Concrete,* American Concrete Institute report SP-55-10, 1978

Also in D. L. Fillmore, "Literature Review of the Effects of Radiation and Temperature on the Aging of Concrete," INEEL/EXT-04-02319, 2004

Figure 3. Tensile strength of concrete exposed to neutron radiation f_{ru} related to strength of untreated concrete f_{ruo}