AN EVALUATION OF CURRENT RECOMMENDATIONS ON HIGH-ENERGY LINEAR ACCELERATOR SHIELDING

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PROBLEM STATEMENT

HOW FAR CAN GUIDELINES TAKE US

HOW FAR CAN MONTE CARLO TAKE US

HOW FAR CAN MEASUREMENT TAKE US

DO WE GET NOWHERE

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SAFETY

HOW MANY TREATMENTS ARE GIVEN KNOWING WHAT IS ACTUALLY DELIVERED DURING TREATMENT?

HOW WELL DO WE PRESCRIBE CONSEQUENCE
- WORKLOAD
- USE FACTOR
- OCCUPANCY FACTOR

NOT ALWAYS COMPARABLE IN RIGOUR

TRENDS

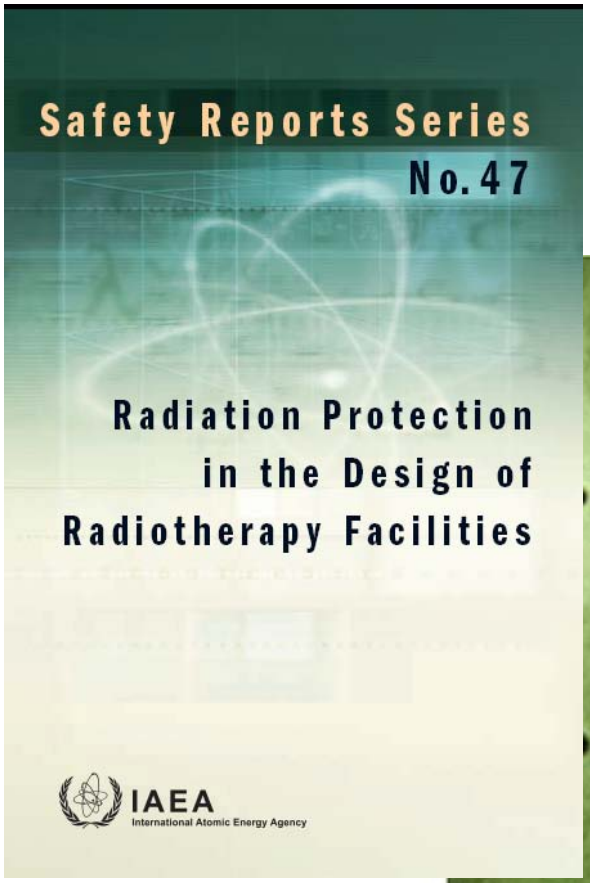
Providers race to offer
Patients demand to receive

IMRT ISN'T NEW

DYNAMIC MULTILEAVES AREN'T NEW

HYPER-FRACTIONATION ISN'T NEW

B U T . . .



NCRP REPORT No. 151

Structural Shielding Design and Evaluation for Megavoltage X- and Gamma-Ray Radiotherapy Facilities

Recommendations of the
NATIONAL COUNCIL ON RADIATION
PROTECTION AND MEASUREMENTS

December 31, 2005

National Council on Radiation Protection and Measurements
7910 Woodmont Avenue, Suite 400/Bethesda, MD 20814-3095

CALCULATION BASED ON GUIDELINES

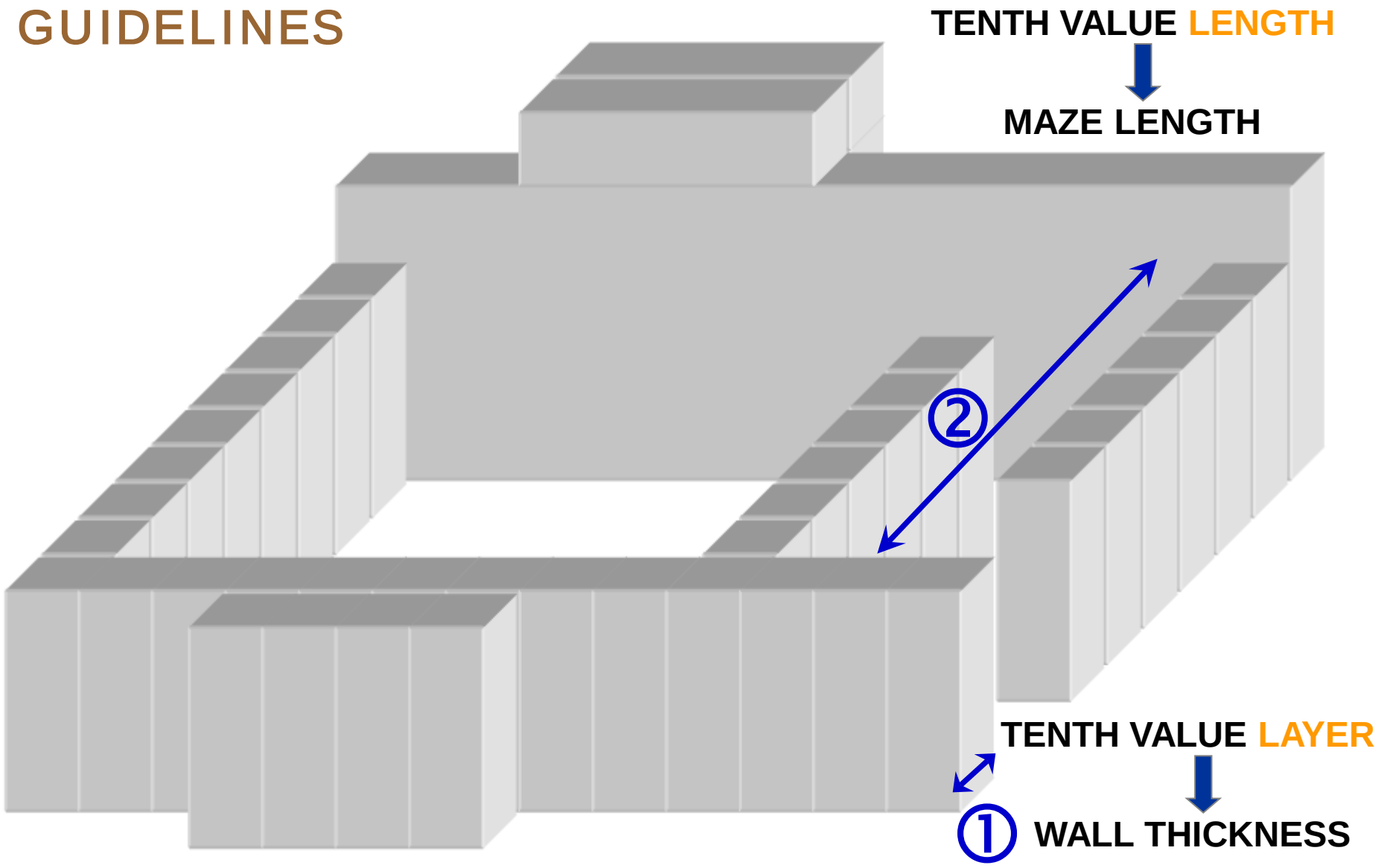


TABLE B.2—*Primary-barrier TVLs for ordinary concrete (2.35 g cm^{-3}), steel (7.87 g cm^{-3}), and lead (11.35 g cm^{-3}) (suggested values in centimeters).*[a]

Endpoint Energy (MV)[b]	Material	TVL_1 (cm)	TVL_e (cm)
		35	30
		9.9	9.9
		37	33
		10	10
		5.7	5.7
		41	37
	Steel	11	11
	Lead		.7
15	Concrete		
	Steel		
	Lead		.7
18	Concrete		
	Steel		
	Lead	5.7	5.7

NOT ENOUGH FOR DESCRIBING THE BEAM

WHICH MAKE

WHICH MODEL

NO ERROR BARS

NOT ENOUGH FOR DESCRIBING THE SHIELD

WHICH LOCALE

WHAT AGE

EXCERPT FROM NCRP151 (2005)

TABLE B.7—*TVLs for leakage radiation in ordinary concrete (suggested values in centimeters).*[a]

Endpoint Energy (MV)[b]	TVL_1 (cm)	TVL_e (cm)
4	33	28
6	34	29
10	35	31
15	36	33
18	36	34
20	36	34
25	37	35
30	37	36
Co-60	21	21

INADEQUATE DESCRIPTION OF RADIATION BEAM

NO INDICATION OF PLUS/MINUS

EXCERPT FROM NCRP151 (2005)

TABLE 4. TENTH VALUE LAYER (TVL) FOR ^{60}Co AND X RAY ENERGIES

(approximate values based on large attenuation)

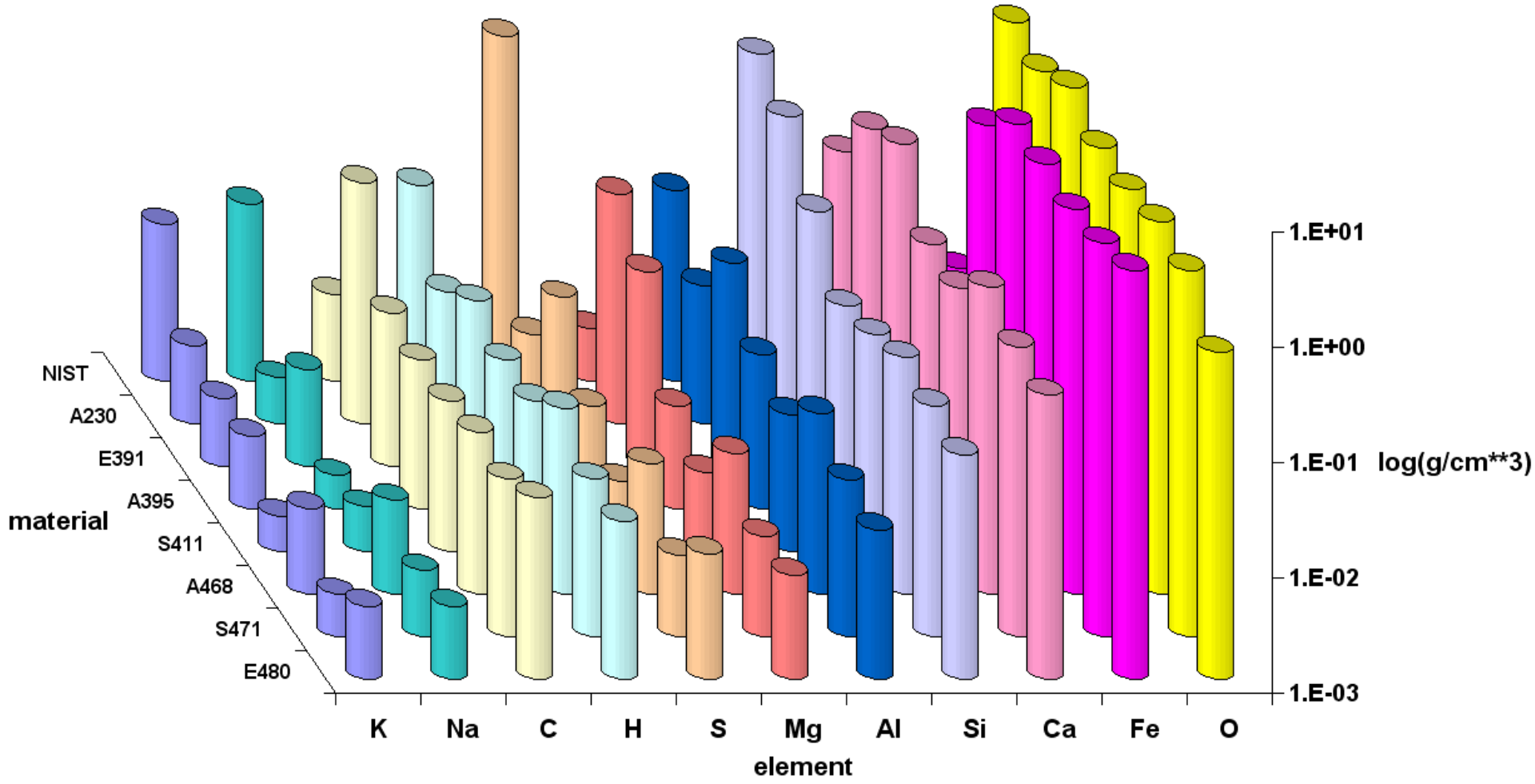
	Co-60[a]	4 MV[b]	6 MV[b]	10 MV[b]	15 MV[b]	18 MV[b]	20 MV[b]	24 MV[b]
TVL for concrete (density 2350 kg · m^{-3}) (in mm)								
Primary beam gamma/ X rays	218	290	343	389				
Leakage gamma and X rays (90°)	218	254	279	305				
TVL for steel (c								
Primary beam gamma/ X rays								
Secondary bear gamma/ X rays					87	87	88	89
TVL for lead (c								
Primary beam gamma/ X rays					57	56	55	52
Secondary beam gamma/ X rays	40	47	45	46	47	47	49	51

AGAIN BEAM NOT PROPERLY DESCRIBED

AGAIN BUILDING MATERIAL NOT PROPERLY DESCRIBED

DOES IT MEAN CAN'T BE 50 OR 52?

EXCERPT FROM IAEA47 (2006)



Elemental composition of 7 concrete samples (adapted from Kase 2002) compared to that of NIST evaluation. Each sample is identified by a letter denoting the manufacturer, followed by its density (x 100 g/cm3). Three manufacturers have been included: ‘A’ for Atomic International, ‘E’ for New England Lead Burning, ‘S’ for Nuclear Shielding Supplies and Services.

OUR MONTE CARLO SIMULATIONS

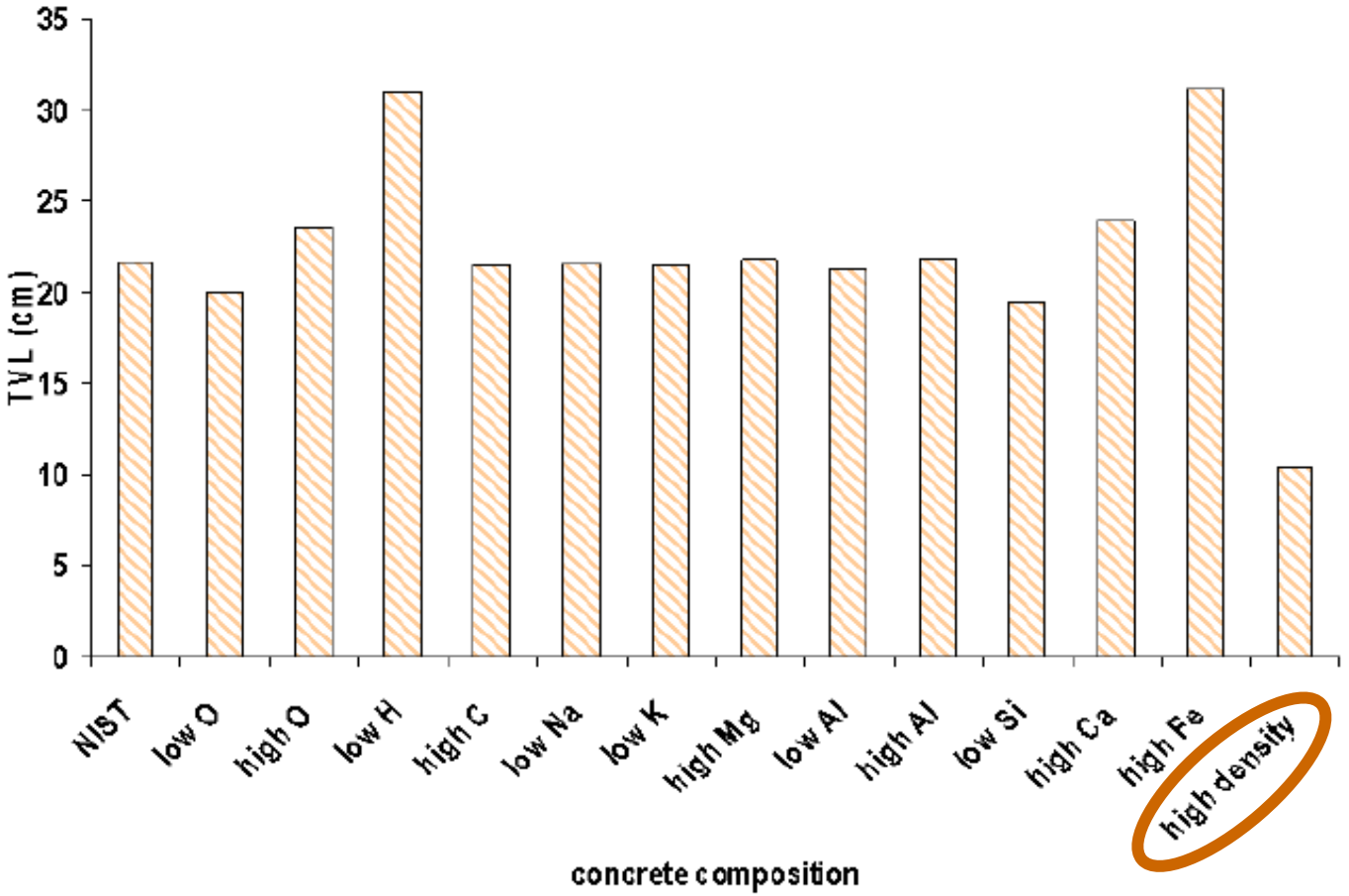


Figure 11. Tenth value layer of neutrons (TVL_n) in concretes of varying compositions and density. While TVL_n for NIST concrete was found to be 21.7 cm, it varied from 19.4 cm to 31.2 cm as the elemental composition was modified; these effects are expected from the neutron interaction cross sections (Figure 9). TVL_n dropped to 10.3 cm when the density of NIST concrete was changed from 2.30 g/cm^3 to 4.80 g/cm^3. Values of TVL_n were derived from the gradient of $\log_{10}$ plots of energy fluence, found by linear least-squares regression of points with standard error ≤ 0.1; the coefficient of determination, commonly known as R^2, was ≥ 0.999 in all cases.

HIGH-DENSITY BUILDING BLOCKS

ADVANTAGE Smaller footprints

WHAT'S IN THE BLOCKS

Manufacturers insist on providing black-box 'solutions'

We have witnessed horror stories

TVLs NOT GIVEN IN GUIDELINES

LIMITED LITERATURE

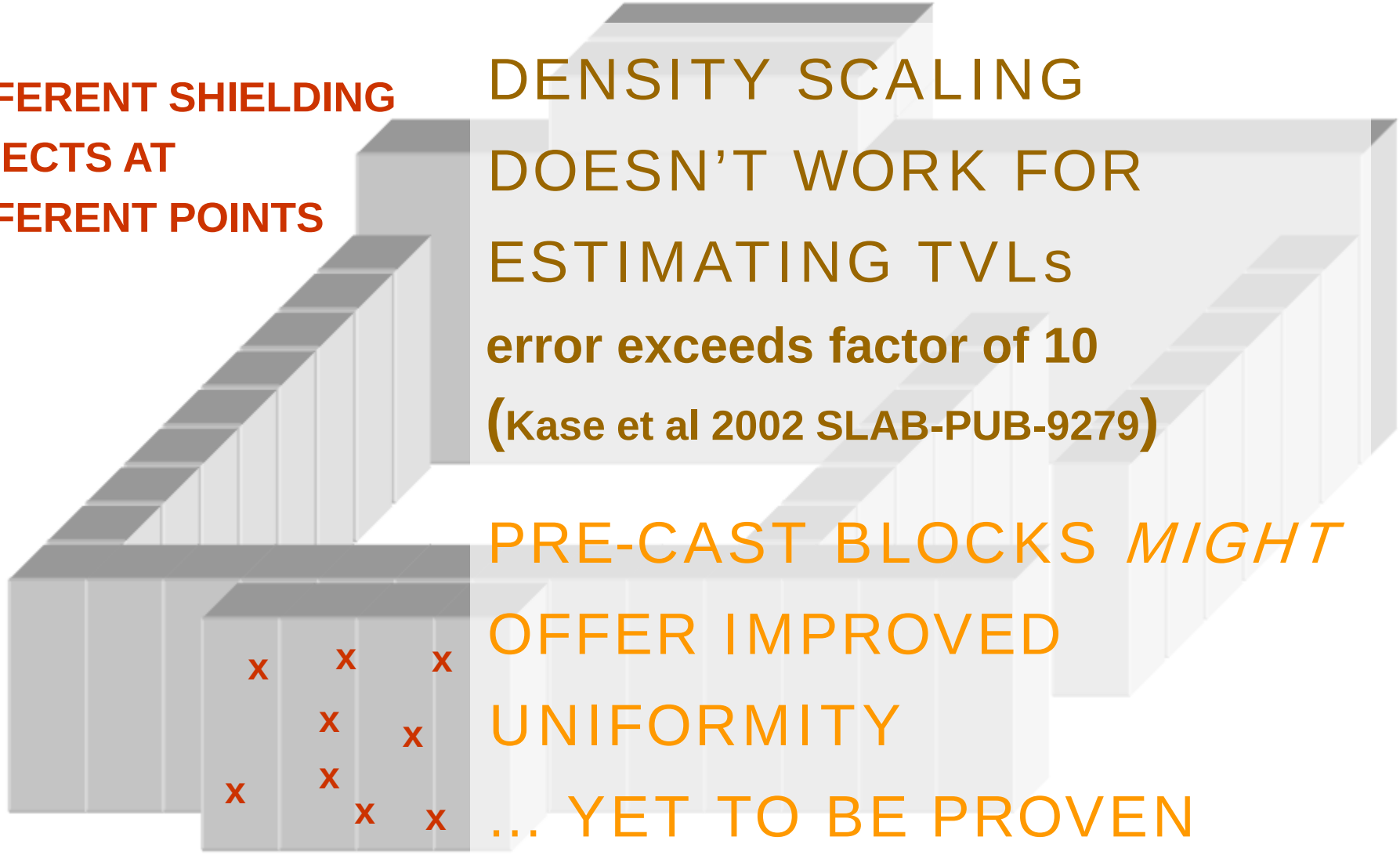
• Ezzell GA 2004 "Shielding evaluation and acceptance testing of a prefabricated, modular, temporary radiation therapy treatment facility" Journal of Applied Clinical Medical Physics 5(4) 120

• Barish RJ 1993 "Evaluation of a new high-density shielding material" Health Physics 64(4) 412

WE NEED MORE SAMPLING & MORE STUDIES

THE PROBLEM WITH NON-UNIFORMITY (DENSITY, MOISTURE‡, COMPOSITION)

DIFFERENT SHIELDING EFFECTS AT DIFFERENT POINTS



DENSITY SCALING DOESN'T WORK FOR ESTIMATING TVLs

error exceeds factor of 10 (Kase et al 2002 SLAB-PUB-9279)

PRE-CAST BLOCKS *MIGHT* OFFER IMPROVED UNIFORMITY

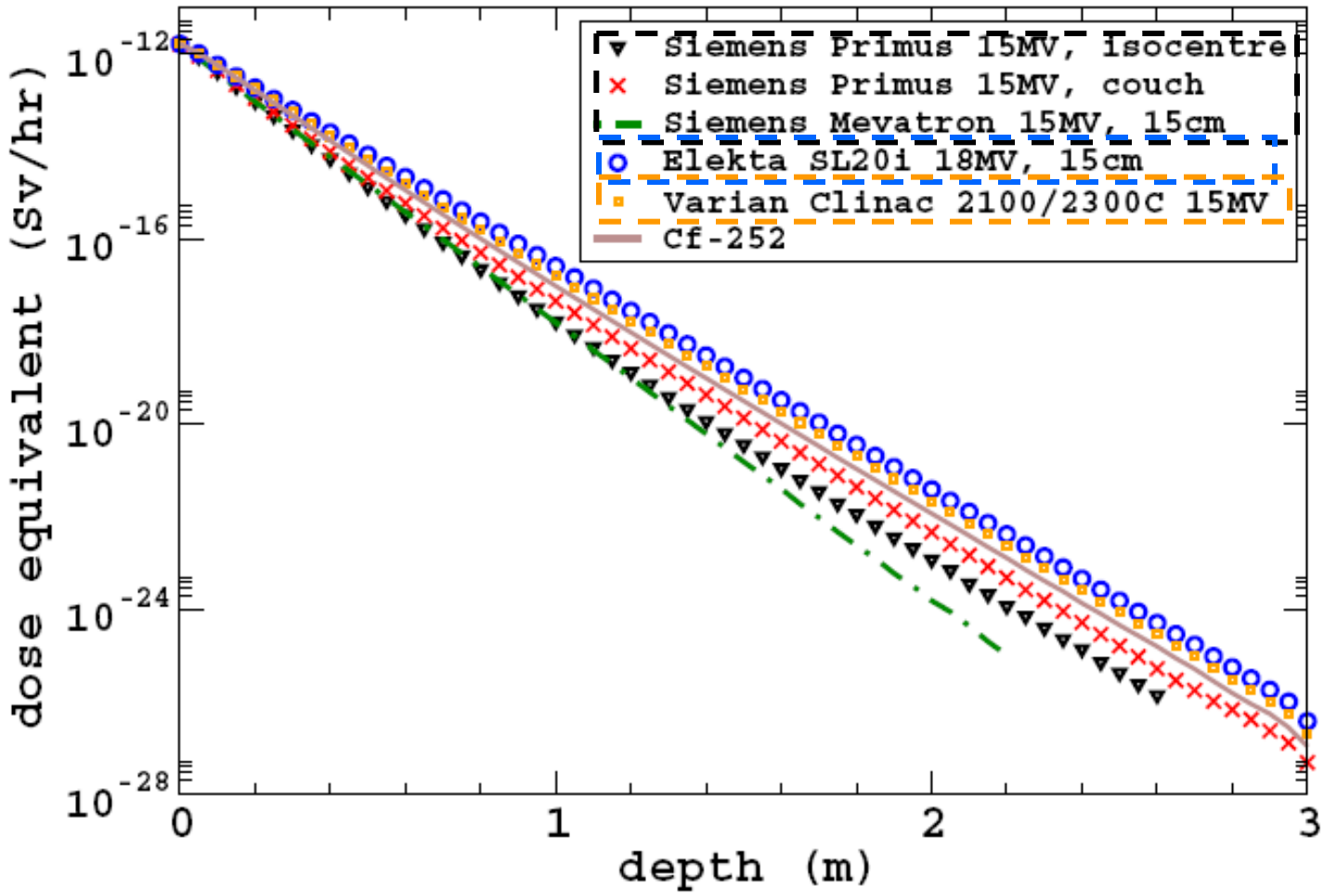
… YET TO BE PROVEN

‡ Tziaka 2007 MSc Dissertation, University of Surrey

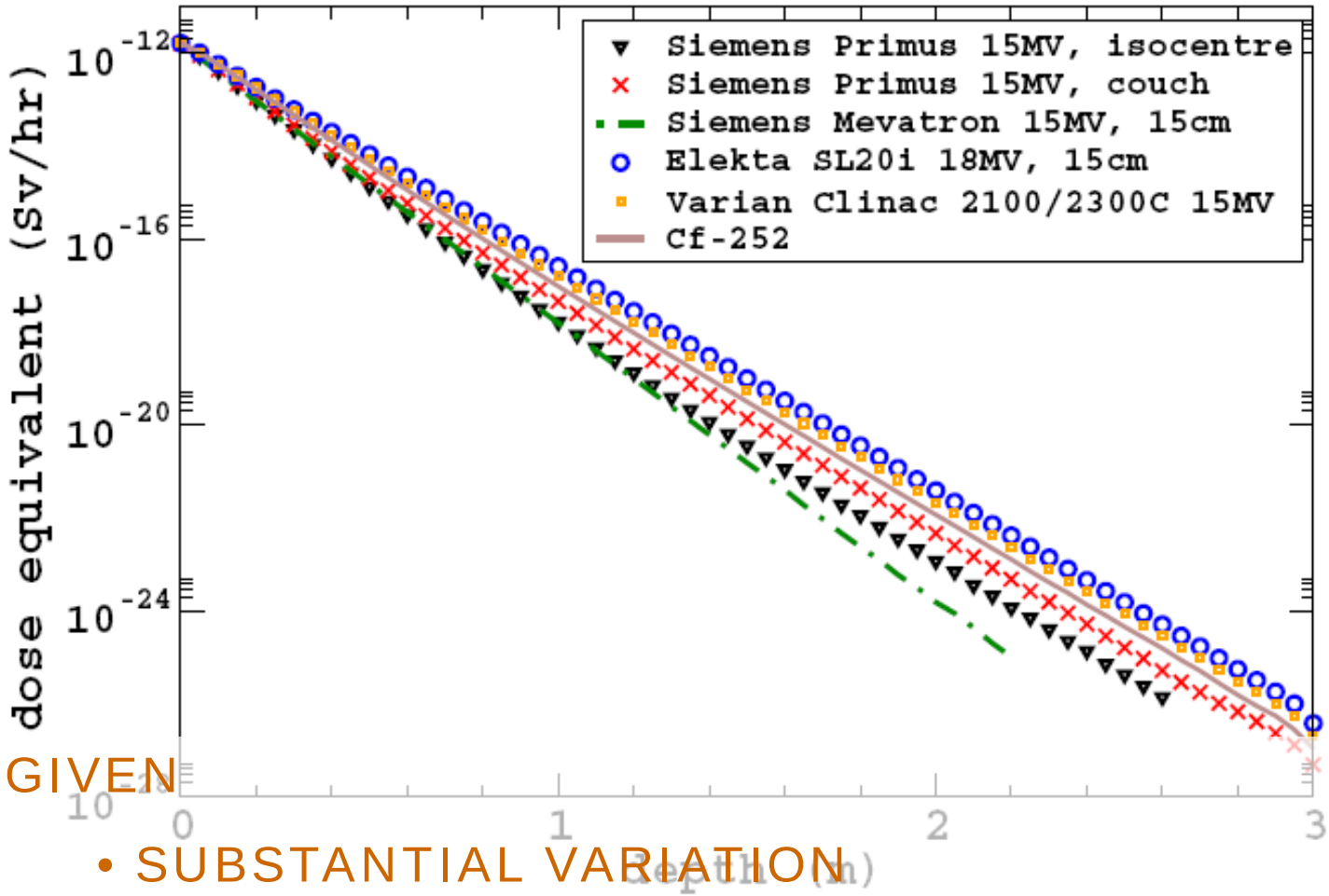
Pena et al 2005 PMB 50

Ongaro et al 2000 PMB 45

Chen et al 2006 NIM-A 562



NOTE VARIATION WITHIN 15MV ALONE

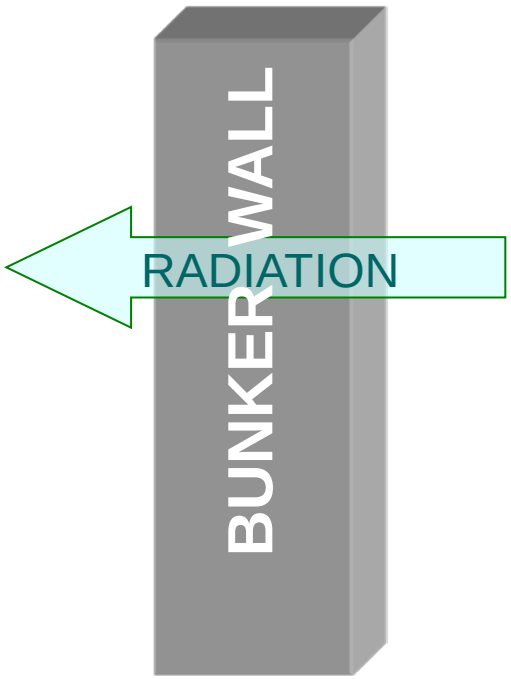


GIVEN

- SUBSTANTIAL VARIATION
- Cf-252 ISN'T OUTLYING

WHAT'S THE POINT OF SIMULATING THE LINAC HEAD, BENDING MAGNET, ETC ETC ETC?

ADDITIONAL SHIELDING CONCERNS



1. PHOTON (TREATMENT) BEAM

NUCLEAR REACTION — CAN'T HELP IT

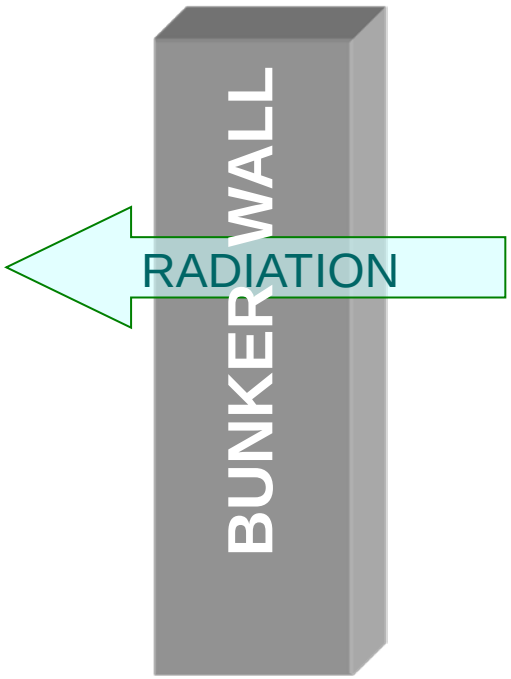
2. NEUTRON CONTAMINATION

NUCLEAR REACTION — CAN'T HELP IT

3. NEUTRON-INDUCED PHOTONS

WHAT RECOMMENDATION* SAYS

*National Council on Radiation Protection and Measurements Report 151 (2005)



1. PHOTON (TREATMENT) BEAM

IF THIS IS OK

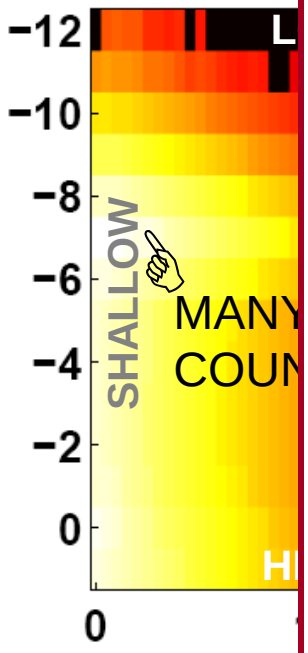
2. NEUTRON CONTAMINATION

THESE WILL BE OK

3. NEUTRON-INDUCED PHOTONS

WE FOUND: NOT QUITE ...

NEUTRONS PHOTONS FROM NEUTRONS



If the material used in the primary barrier is concrete (whether ordinary or heavy; see Sections 4.3.1 and 4.3.2), then experience has shown that the barrier will adequately absorb all photoneutrons and neutron capture gamma rays and no additional barrier is required. This is due to the relatively high hydrogen content of concrete and its resultantly high neutron absorption cross section. If, on the other hand, materials other than concrete are used in the primary barrier, then special considerations are required and these are covered in Section 2.2.3.

Typical workloads are discussed in Section 3. Though modern techniques such as IMRT are known to require very large numbers of monitor units or beam-on time, these techniques may use very

Note RESULTS SHOWN HERE EXCLUDES DELAYED GAMMA

MCNPX 2.4.0 DOES NOT SIMULATE DELAYED GAMMA

SIMULATION WAS DONE USING MCNPX 2.4.0

ALTHOUGH IN SOME CASES ARTIFICIAL LINES HAVE BEEN INCLUDED IN THE CROSS SECTIONS

> The delayed gamma ray at an energy of 1.7791 MeV from the reaction $n + {}^{27}Al \rightarrow {}^{28}Al \rightarrow {}^{28}Si + \beta^- + \gamma$ has been included in the thermal-capture photon-production data form these two ZAIDs (FRA02). [MCNPX manual]

BETA VERSIONS 26C/D DO SIMULATE DELAYED GAMMA

HOWEVER, DUE TO MULTIPLE GLITCHES WE FOUND THE CAPABILITY NOT READY FOR OUR USE **[Chin & Spyrou 2007. Monte Carlo simulation of (γ, n) and (n, γ) activations: a multi-code comparison with theory. 12th Int Conf Modern Trends in Activation Analysis. Tokyo,]**

WHEN THINGS WENT WRONG

Sequence of events in bunker-building

between under- and over-shielding

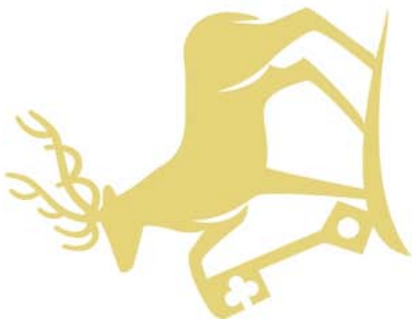
CAN'T WE GET IT JUST RIGHT?

AND LEARN THE LESSON

AND START TO WONDER: IS THE SURVEYMETER OK?

IT IS COMMON TO OVER-SHIELD

- to play safe
- not to exclude future upgrades to higher MV
- to account for various uncertainties
- WE DON'T KNOW HOW TO GET IT *JUST RIGHT*



"IF GUIDELINES AREN'T GOOD, LET'S GO FOR MONTE CARLO, THE GOLD STANDARD!"

BUT THEN MONTE CARLO ISN'T GOING TO DO ANY MAGIC

HOW FAR CAN MONTE CARLO TAKE US?

GARBAGE IN, GARBAGE OUT

INPUT UNCERTAINTIES

before we worry about output uncertainties

WE CAN'T DESCRIBE EXACTLY

material composition, radiation source, non-uniformity

MONTE CARLO MODELLING OF THE RADIOTHERAPY LINAC

PHOTON & ELECTRON FIELD	NEUTRON FIELD
CAN GET IT *RIGHT ENOUGH*	**CAN NEVER GET IT RIGHT**

RADIOTHERAPY PHYSICISTS CONSIDER NEUTRONS ‘EXOTIC’; *NEUTRON EXPERTS* LACK RADIOTHERAPY EXPERIENCE

OBVIOUS FROM WRONG TERMINOLOGY

PHOTON NOMINAL ENERGY SHOULD BE IN ‘MV’ BUT MANUFACTURERS PROVIDE DATA FOR FLATTENNING FILTER, TARGETS, COLLIMATORS etc, BUT NOT BENDING MAGNET & SURROUNDING SHIELDING

MONTE CARLO MODELLING OF THE RADIOTHERAPY LINAC

PHOTON & ELECTRON FIELD

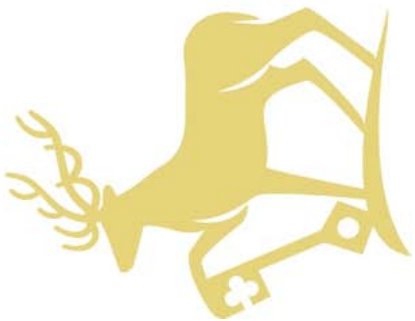
ELECTRON ENERGY & SPOT SIZE

tweak to match

MEASURED 3D DOSES IN WATER PHANTOM

NEUTRON FIELD

PRODUCTION PARTICULARLY SENSITIVE TO ENERGY DUE TO STEEP GRADIENT ON THE GIANT DIPOLE RESONANCE



HOW FAR CAN MEASUREMENTS TAKE US?

1. CAN'T MEASURE BEFORE BUNKER EXISTS

2. STANDARD INSTRUMENTS CAN'T COPE WITH PULSED BEAMS & HIGH PHOTON-TO-NEUTRON FLUENCE RATES

AND BY THE WAY…

THE LARGEST FIELD SIZE MAY NOT BE THE WORST CASE

Mao, Kase, Liu et al 1997 "Neutron sources in the Varian Clinac 2100C/2300C medical accelerator calculated by the EGS4 code" Health Physics 72(4) 524

Alfuraih, Chin, Spyrou 2007 "Activation analysis in a high-energy linear accelerator radiotherapy facility" 12th Modern Trends in Activation Analysis, Tokyo

0º, 90º, 180º, 270º GANTRY ANGLES MAY NOT BE THE WORST CASES

UNPUBLISHED MEASURED DATA: READING AT 290º HIGHER THAN THOSE AT 0º, 90º, 180º, 270º AND 225º, BELIEVED TO BE DUE TO NEUTRON SCATTER

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SO ...

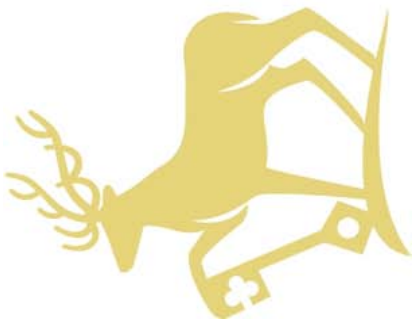
GUIDELINES

MONTE CARLO

MEASUREMENT

DO NOT TAKE US VERY FAR

THE WAY FORWARD ...



GUIDELINES SHOULD BE COMPLEMENTED WITH

REMEDY-FRIENDLY DESIGNS

LIST OF DON'Ts / DBASE OF BLUNDERS (things to avoid)

REMEDIES HOW-TO (when shielding fails)