Errors in Radiation Oncology

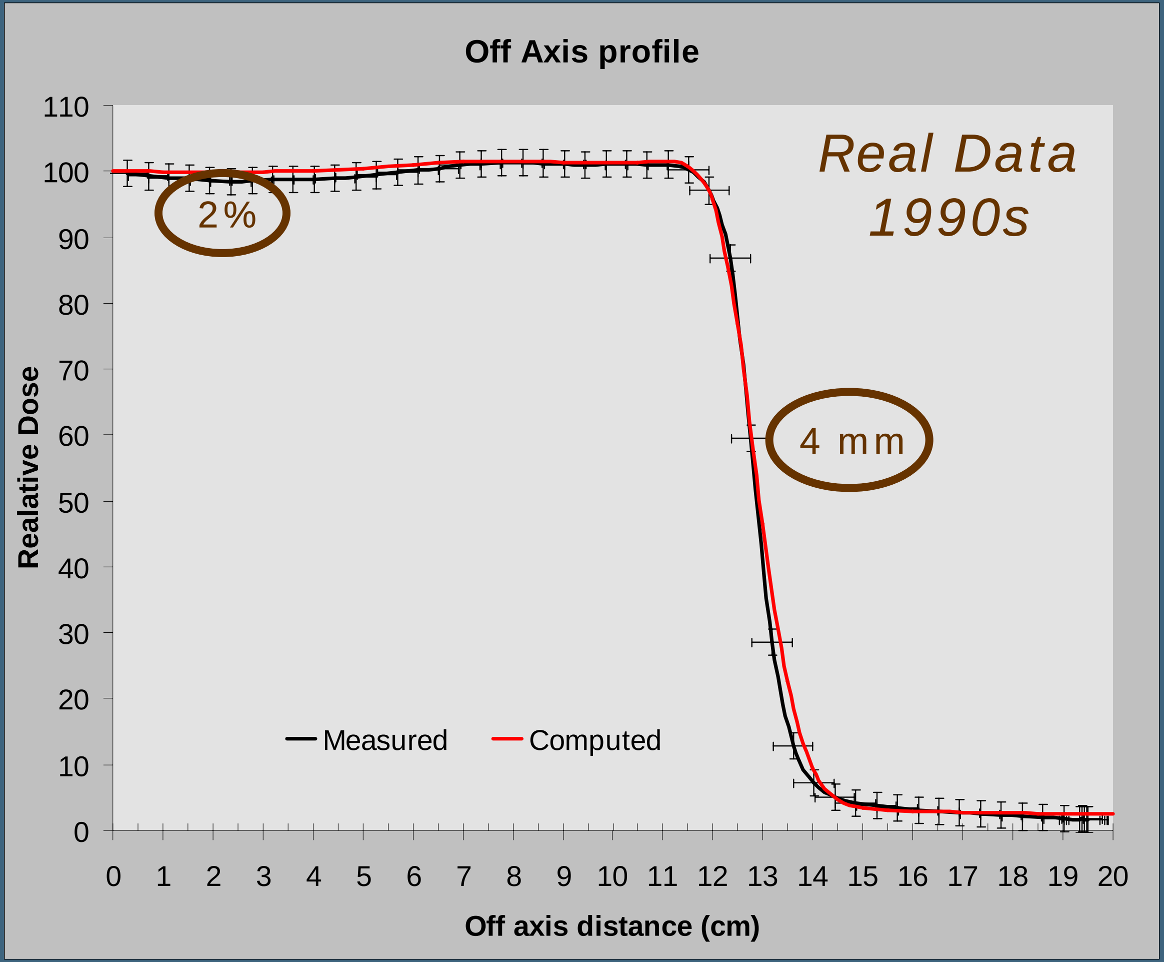
Geoffrey S. Ibbott, Ph.D.

with slides from

Jake van Dyk

ICRU Goal in Dose Calculation and Spatial Accuracy

- *ICRU 42, 1987 Recommends*
- Relative dose accuracy in uniform dose region: **2%**
- Spatial accuracy in high dose gradient: **2 mm**



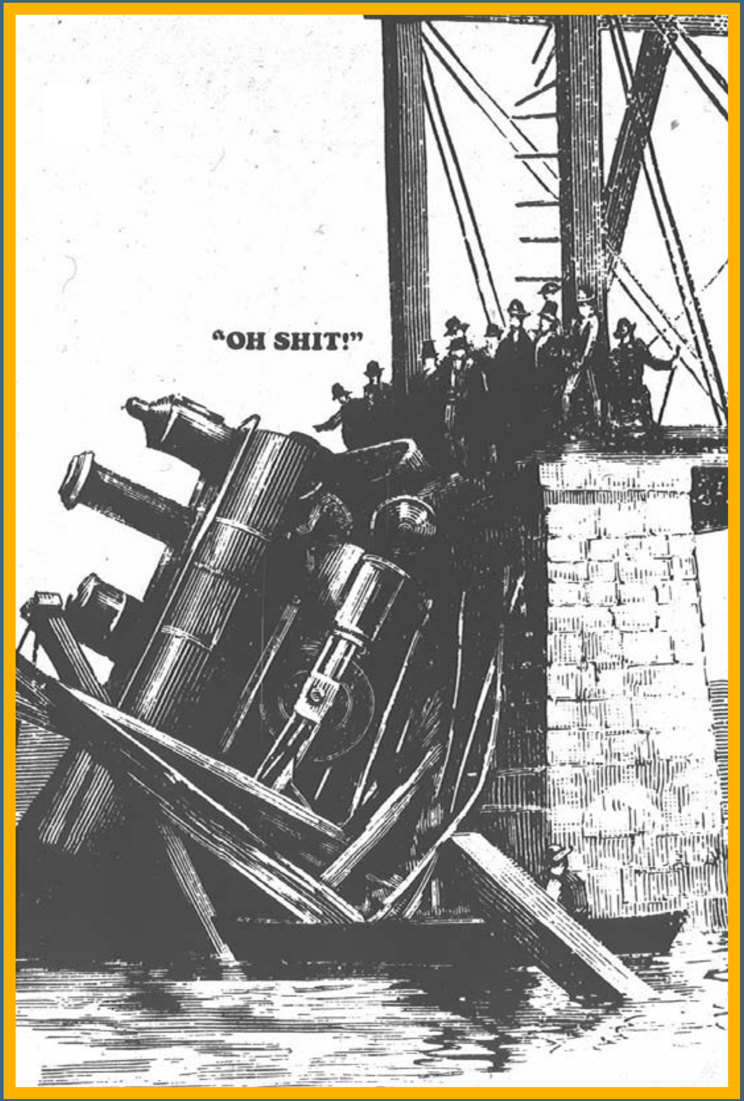
Errors in Radiation Oncology

- Error
  - “The failure of planned action to be completed as intended (i.e., error of execution) or the use of a wrong plan to achieve an aim (i.e., error of planning).”

Institute of Medicine. To Err is Human: Building a Safer Health System, 2000.

Euphemisms for "Errors"

- Accidents
- Incidents
- Misadministrations
- Unusual occurrences
- Discrepancies
- Adverse events



Medical Errors - General

TO ERR IS HUMAN

Building a Safer Health System

- In United States…
- Annual errors
  - 44K-98K people die from medical errors
  - More than motor vehicle accidents, breast cancer or AIDS
  - Total annual cost $37.6 to $50 billion
- Most common types
  - Technical (44%)
  - Diagnosis (17%)
  - Failure to prevent injury (12%)
  - Use of drugs (10%)

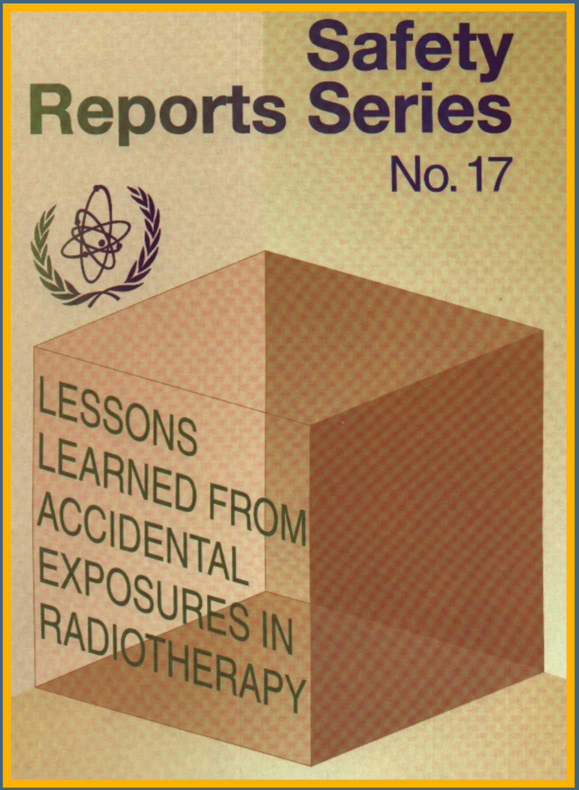
Institute of Medicine. To Err is Human: Building a Safer Health System, 2000.

Medical Error Analysis

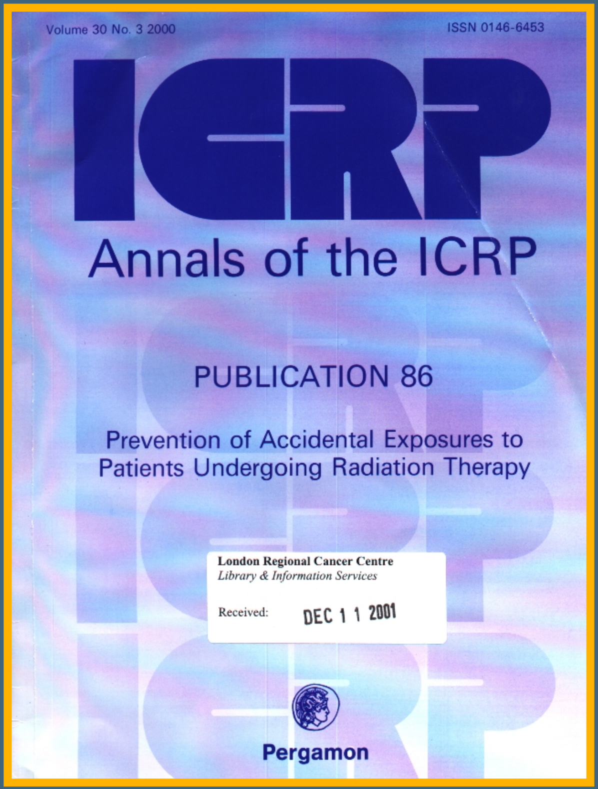
Recently, more public & acceptable practice

- Sample references - medicine in general
  - *Institute of Medicine. To Err is Human: Building a Safer Health System, 2000.*
  - *Sokol & Molzen. The Changing Standard of Care in Medicine, J Legal Med, 2002.*
  - *Baker et al. The Canadian Adverse Events Study: the incidence of adverse events among hospital patients in Canada. CMAJ 2004.*
- Sample references - RT
  - *Macklis et al. Error Rates in Clinical Radiotherapy. J Clin Oncol, 1998.*
  - *Cosset. ESTRO Breur Gold Medal Award Lecture 2001. Irradiation Accidents - Lessons for Oncology? Radioth Oncol, 2002*

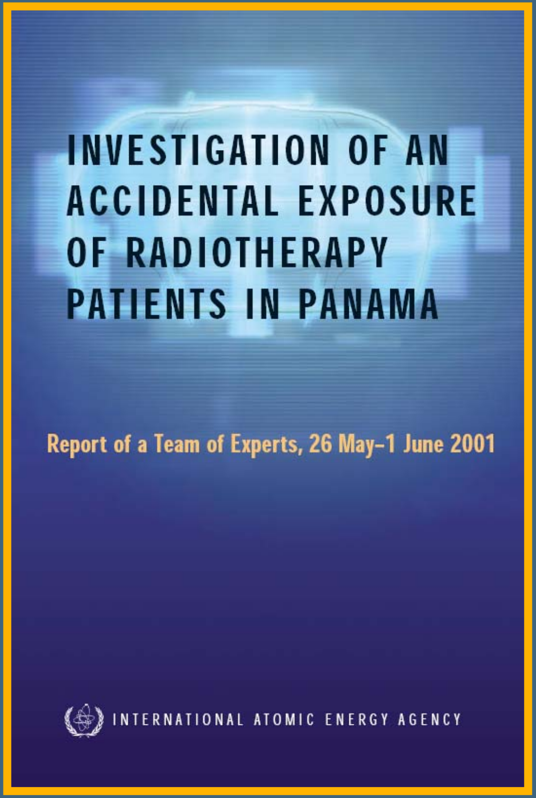
Reports of Errors in RT



IAEA 2000



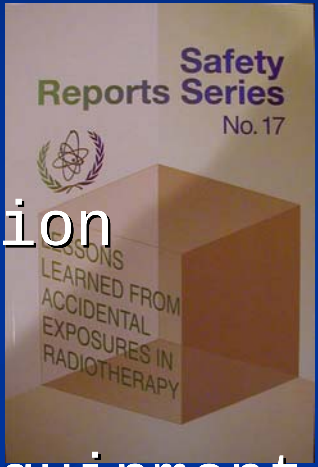
ICRP 2000



IAEA 2001

Radiation Accidents

- The IAEA has tabulated 92 accidental exposure events
  - Radiation measurement systems
  - Machine commissioning & calibration
  - Treatment planning
  - Patient setup and treatment
  - Decommissioning of teletherapy equipment
  - Mechanical and electrical malfunction
  - Brachytherapy/LDR sources and applicators
  - Brachytherapy/HDR
  - Unsealed sources



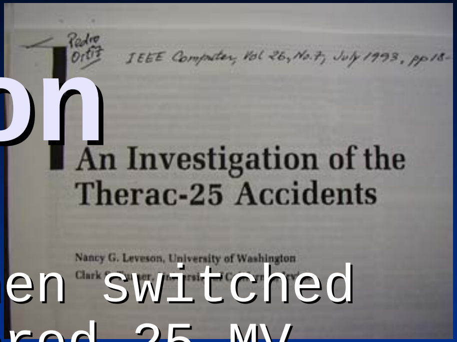
Radiation Measurement Systems

- Incorrect use of calibration report
  - Report specified $N_{D,w}$ but was interpreted as N_k
- Correction for atmospheric pressure (Bend, OR)
  - Institution had no in-house barometer
  - Physicist used airport or transported aneroid barometer
    - Airport reported pressure corrected to sea level (elevation was actually ~3,500 ft.)
    - Aneroid barometer made one complete revolution (4”) and appeared to indicate sea level pressure
  - Patients received 13% overdose

Error in Machine Calibration

- Cobalt unit calibration errors
  - At source replacement, used 30 sec rather than 0.3 min (166% overestimation of exposure time)
- Physicist decayed ^{60}Co activity using graph paper (Riverside Hospital)
- Asymmetric jaws calibrated with chamber on central axis, in penumbra
- Treatment in “Physics” mode
  - Target, flattening filter and monitor chamber not deployed in one beam energy
- Calibration at 10 cm depth interpreted as d_{max}
  - 50% overdose

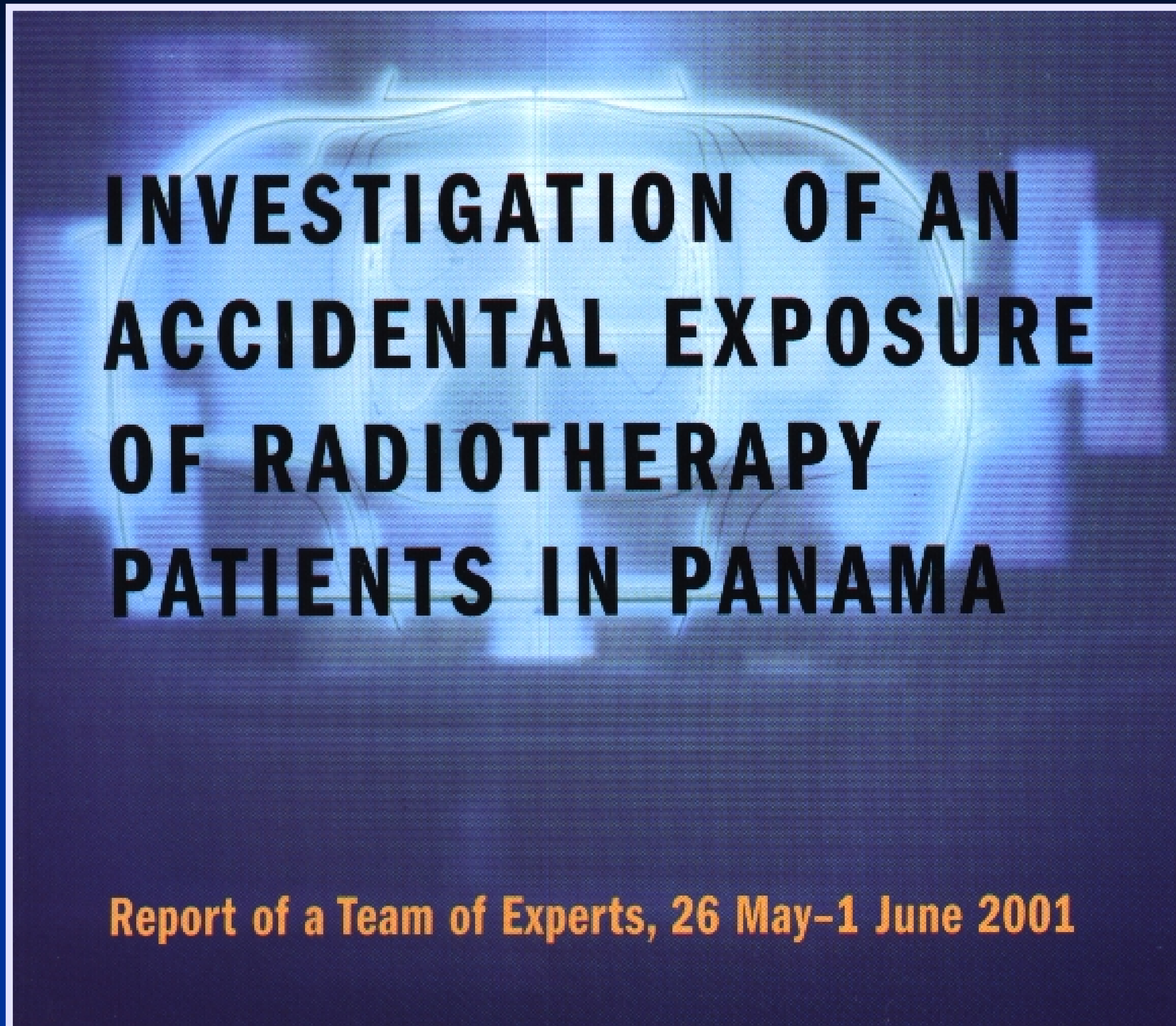
Machine Operation



- "Malfunction 54"
  - If operator selected 25 MV x rays then switched quickly to electrons, machine delivered 25 MV electrons with high beam current, no target and no flattening filter.
    - Monitor chamber switched beam off promptly, but patient had received 160-180 Gy.
    - Malfunction occurred at four hospitals before problem recognized and acknowledged by manufacturer
- Zaragosa, Spain
  - Serviceman didn't recognize bending magnet failure
    - Accelerator automatically delivered maximum beam energy
    - Beam steering failed, high recombination losses led to low monitor response and high patient doses

Treatment Planning System

- Inconsistent sets of basic machine data
  - Calculations with one set resulted in 10% underdose
- Wedge factor incorporated by TPS, also by operator calculating MU setting
- Incorrect application of $1/r^2$ for isocentric treatments when already applied by TPS
- Error by TPS when blocks entered clockwise vs counter-clockwise (Panama)

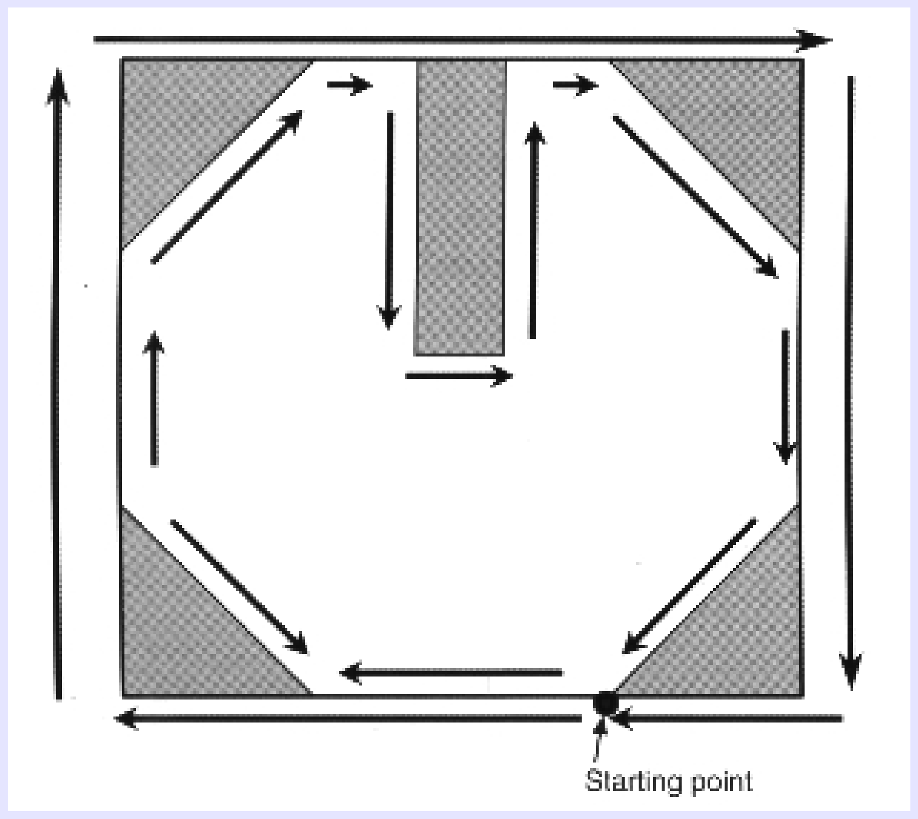

INVESTIGATION OF AN ACCIDENTAL EXPOSURE OF RADIOTHERAPY PATIENTS IN PANAMA

Report of a Team of Experts, 26 May–1 June 2001

IAEA

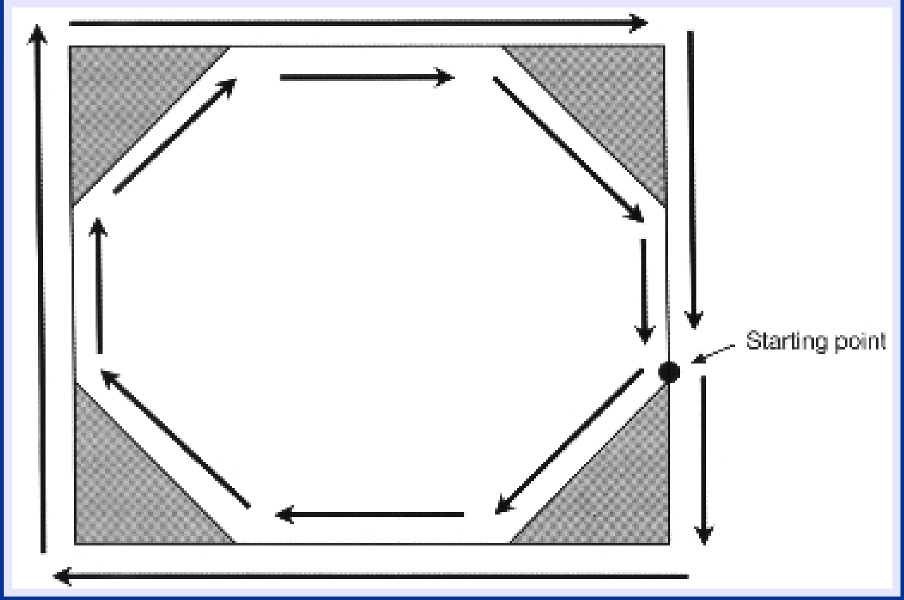
Treatment Planning Fix

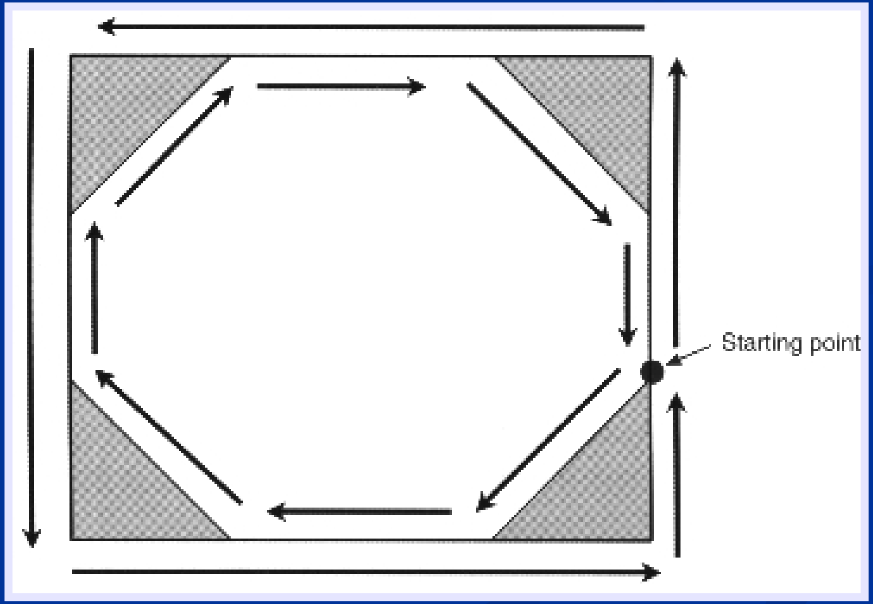
- “Shortcut” method of block entry because >4 blocks



Treatment Planning Fix

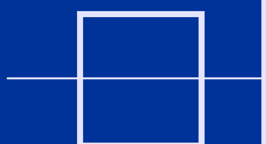
- "Shortcut" method of block entry even when 4 blocks



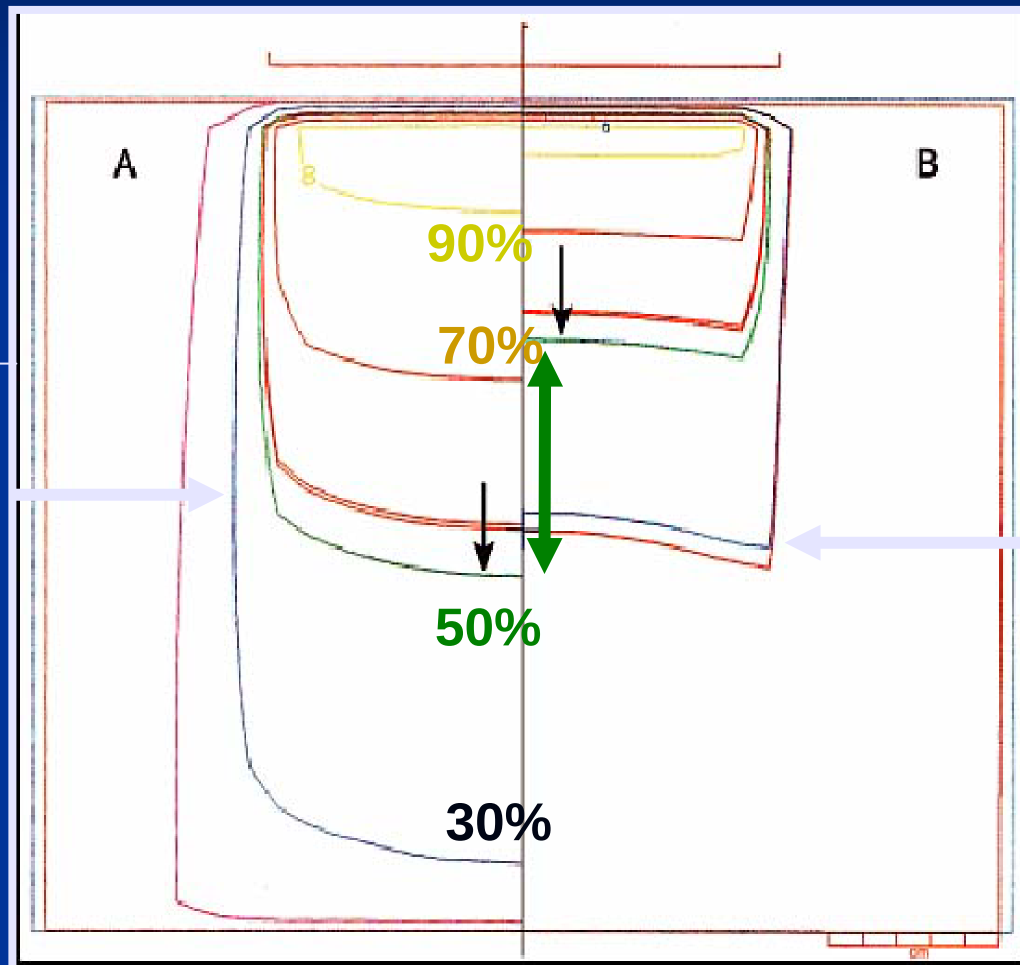


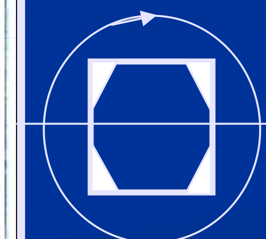
Note: Two approaches

Identification of Problem



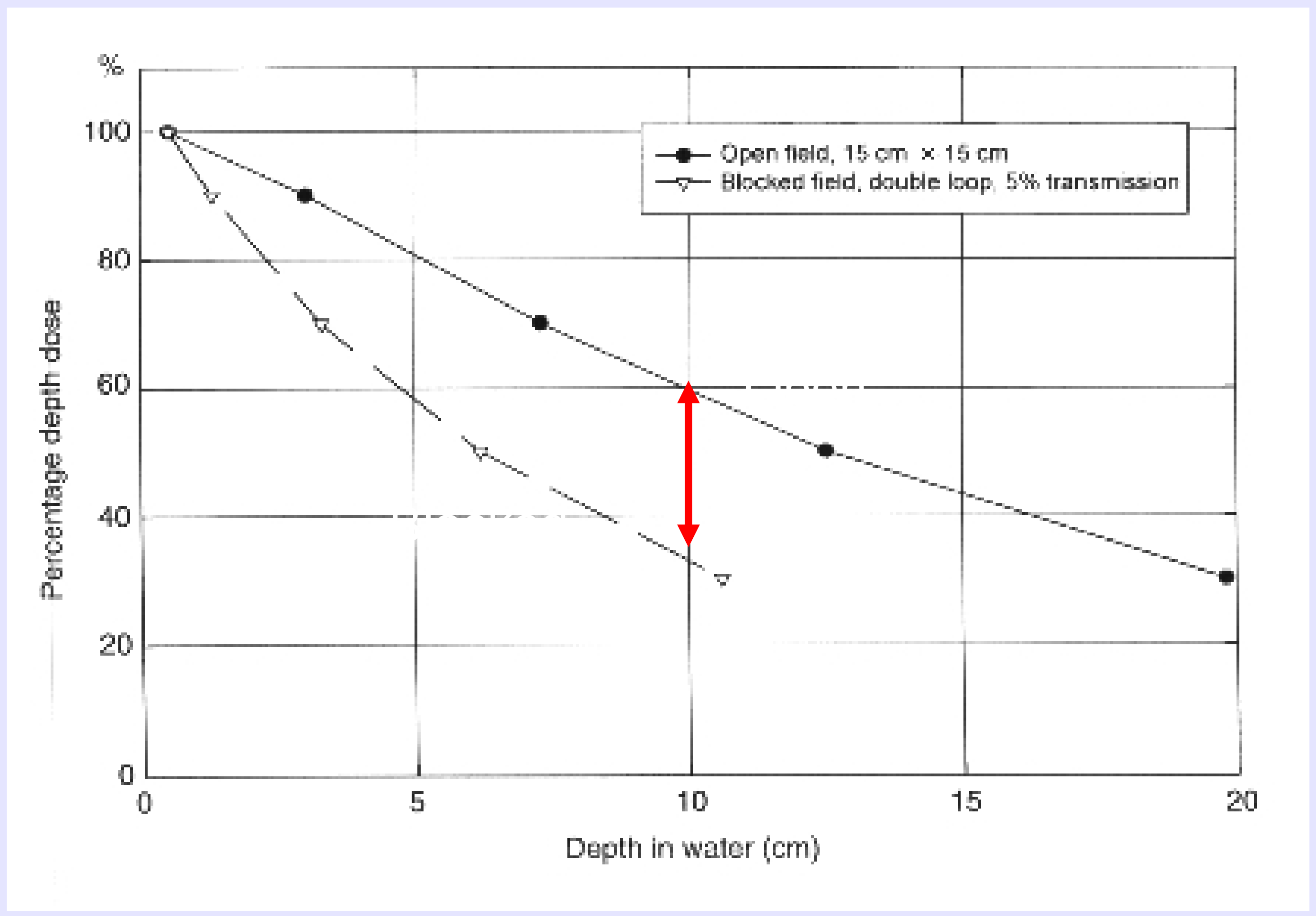
Open beam





Blocks entered together with two CW contours

RTPS Calculated Central Axis Data



Differences lead to overdosing by ~ × **2**

Clinical Summary - March 2002

- 28 patients treated with incorrect doses
  - 17 have since died
  - 13 had rectal complications

Factors Contributing to Errors

- Inadequate instructions in the RTPS manual
- Insufficient QA in treatment planning process
  - No manual checks
  - No written procedure of changes when entering the blocks
- Work organization
- Excessive workload
- Lack of coordination between members of radiation therapy team

Physicists Jailed

November 2004

Two of the indicted physicists are condemned to four years in prison and barred to practice their profession for seven years. They appeal the sentence. The third physicist is acquitted.

Errors in RT: Contributing Factors

- Insufficient education
- Lack of procedures/protocols as part of comprehensive QA program
- Lack of supervision of compliance with QA program
- Lack of training for “unusual” situations
- Lack of a “safety culture”

Errors Related to Modern Technology

- IMRT
  - Example error
    - Error in transferring plan data to machine
    - Transferred open field data but not leaf sequence
    - Full dose given with open field
  - RPC phantom data
    - Later…
- Gamma Knife
  - Wrong side of brain treated – coordinates were reversed

Complexity of Modern RTPS

- Many issues to address
  - Hardware
  - Software
    - Use of images, 3-D, IMRT, optimization, plan evaluation
  - Networking
    - Dosimetry devices
    - Imaging devices
    - Treatment machines
    - Oncology information system
    - Physicians'/physicists' offices/homes
- Some capabilities not easy to test

LDR Brachytherapy

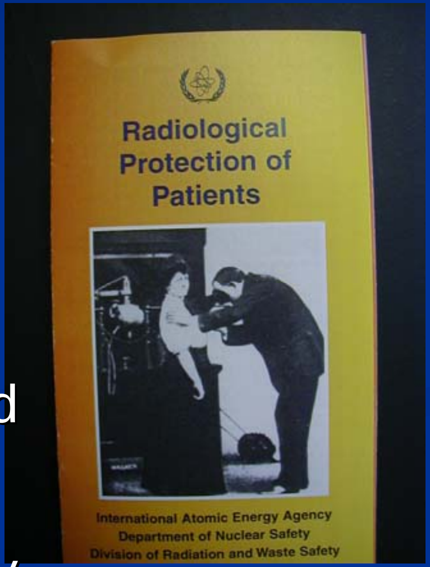
- TPS required entry in R cm^2 h^{-1} rather than μGy m^2 h^{-1}.
- TPS required entry in mg-Ra-eq rather than mCi
- ^{125}I sources ordered with wrong activity (4 mCi vs 0.4 mCi)
- Calculations based on wrong nuclide
- ^{137}Cs source strengths incorrect
- ^{137}Cs source with no activity mixed in with inventory
- Lost sources
- Patient left hospital with sources in place
- Sources not removed properly or at termination of treatment

HDR Brachytherapy

- Indiana, PA
  - Source would not enter one of 5 catheters (had already broken off inside another catheter)
  - Staff discontinued treatment, ignored area radiation monitor alarm, misinterpreted console indications
  - Patient with source still in catheter, transported to nursing home
  - After 4 days, catheter fell out, placed in trash
  - Trash disposal company detected radiation
  - Patient received dose resulting in death, 94 other staff received radiation exposures.

Lessons Learned

- Resources: Adequate, trained personnel
- Identification of safety critical activities:
  - Commissioning, validation
  - Periodic calibration, QC
  - Proper decommissioning of sources
  - Identification of patient
  - Prescription understood, communicated accurately
  - Treatment procedures understood and modifications communicated accurately
  - Planning system, procedures and data confirmed, verified, and documented
  - Sources calibrated, identified and inventory checked



Prevention and Mitigation

- Clear job descriptions, assignment of responsibilities and lines of authority
- Anticipation of unplanned or unusual situations
- Appropriate actions:
  - Change in supplier
  - Change in routine dose or treatment procedure
  - Introduction of new or unusual procedure
- Accurate communication
- Equipment maintenance, proper operation
- Documentation
- Integration of safety and quality assurance