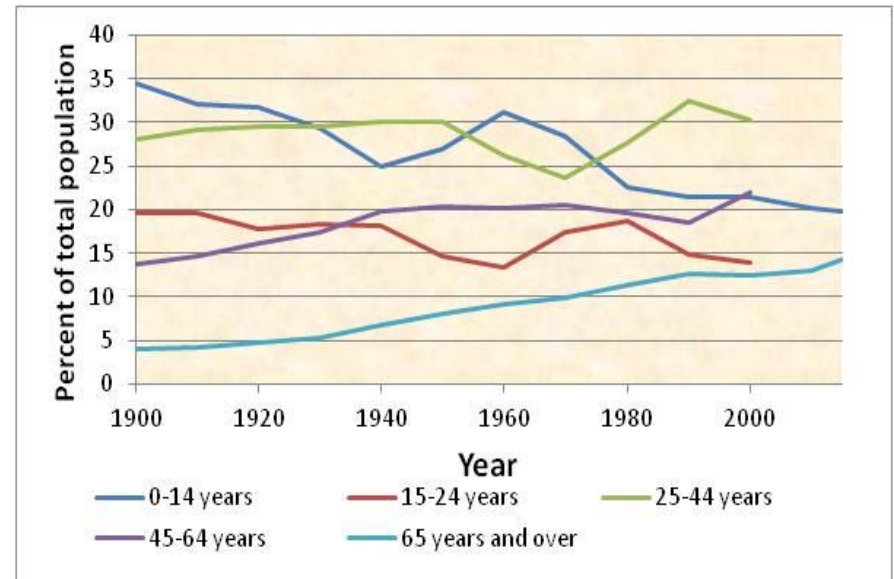
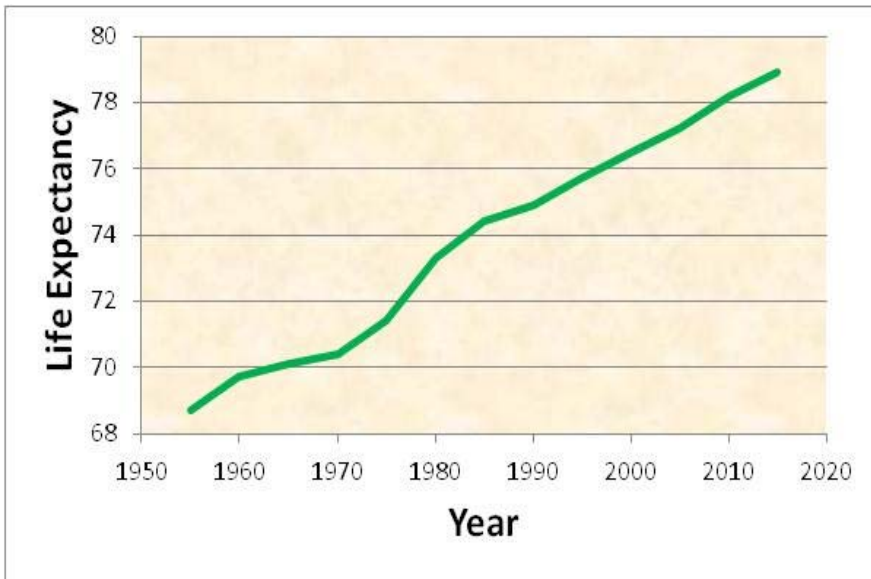


# Radiation Therapy of Patients with Cardiac Implantable Devices: Dosimetric Evaluation and Clinical Management



**Iris Z Wang, PhD DABR FAAPM**  
**September 6<sup>th</sup>, 2019**

# Are we living longer?



“Seemed more patients with pacemakers these days”

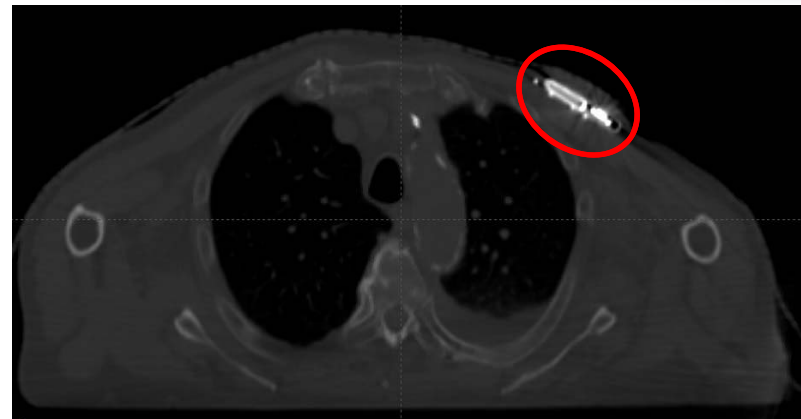
# When we see this in the images...



“Is that a pacemaker?!”

“Why nobody told us?!”

RTT



“Do I have to contour this?!”

“What is the dose limit?”

“What planning technique should I use? .....

CMD

# Outline

- Introduction
  - Arrhythmia
  - Cardiac Implantable Electronic Devices (CIED)
  - Photon interactions
- CIED Errors
- Out-of-field dose
  - TG 34: no direct beam
  - TG 158
- Guidelines
  - Cumulative dose
  - Risk categories
  - Clinical management
- Policy and procedure

Q & A



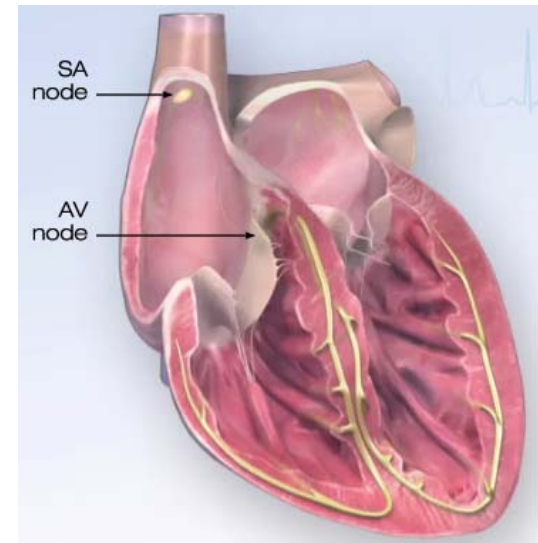
# Introduction

- Arrhythmia
- CIED
- Photon interactions\*

\*This presentation will focus mainly on MV EBRT

# Arrhythmia

- Abnormal heart rhythms
- Natural pacemaker – SA node
- Causes
  - Abnormal rhythm from SA node
  - Interrupted conduction pathway
  - Impulses from other heart tissue



Ref: <https://www.heart.org/en/health-topics/arrhythmia/about-arrhythmia> Last accessed 9/4/19

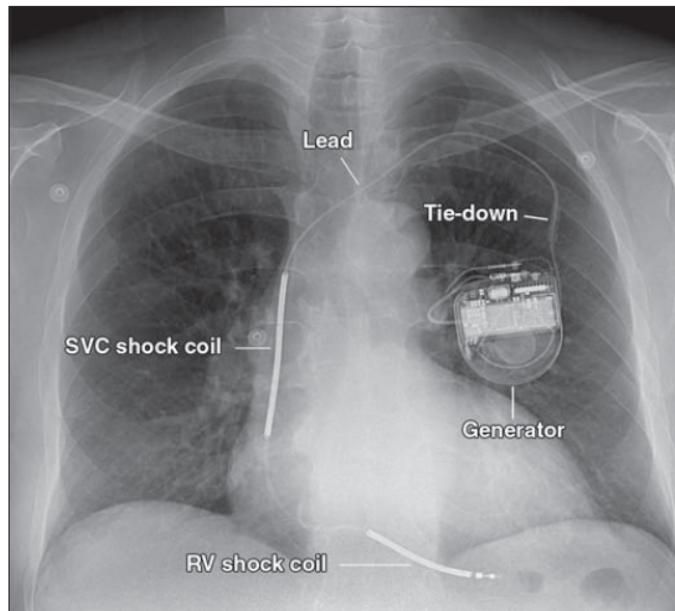
# CIED

## Cardiac Implantable Electronic Devices

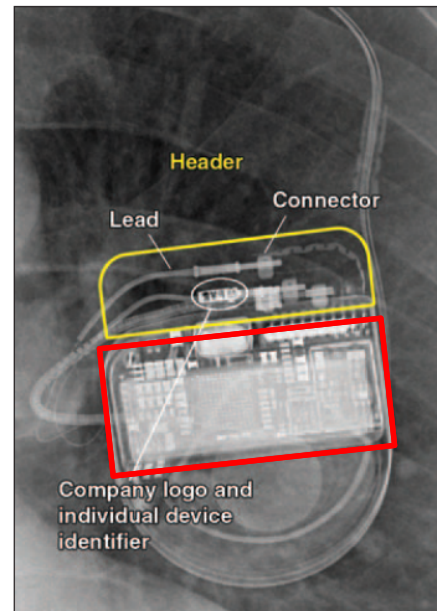
- Implantable Cardiac Pacemaker (ICP)
- Implantable Cardioverter Defibrillator (ICD)
  - Newer ICDs – both pacemaker and defibrillator



# CIED - components



A



B

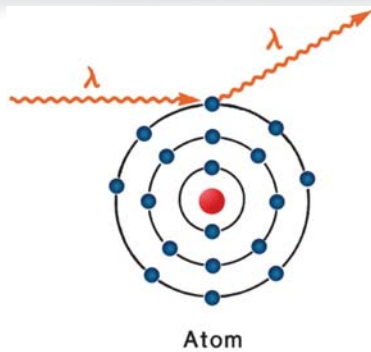
## Pulse Generator

- Capacitors
- Semiconductor Chips
- Battery

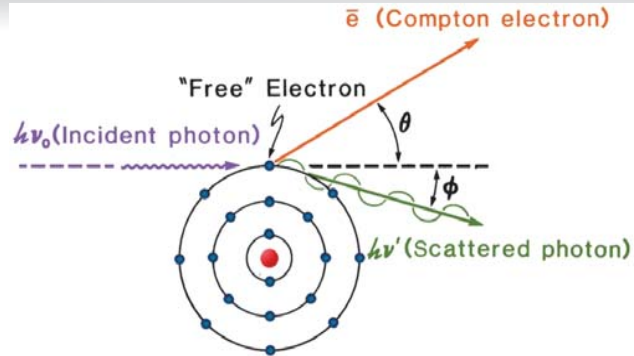
Ref: C M Costelloe et al., AJR 2012; 199:1252-1258



# Photon interactions

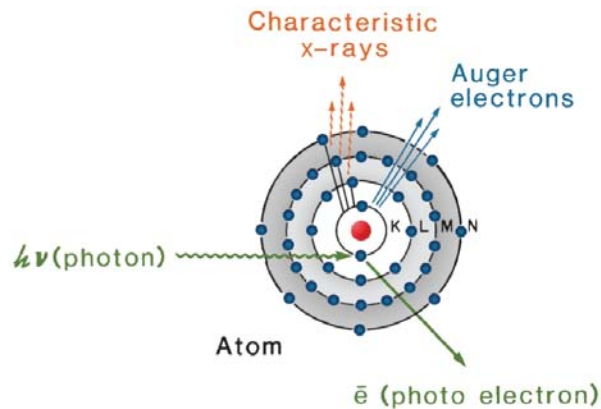
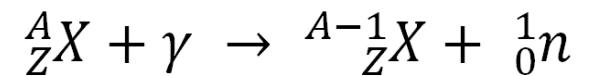


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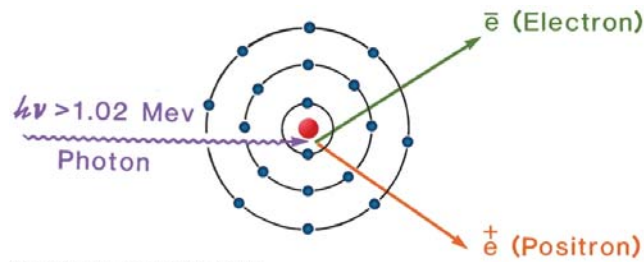


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Photodisintegration



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Photoneutron contamination when > 10 MV !!!

Ref: F Khan et al., Khan's Lectures Handbook of the Physics of Radiation Therapy, 2011

# Potential CIED errors

- By ionizing radiation
- By Electromagnetic Interference (EMI)

# Potential CIED errors by ionizing radiation

- Altered stimulation (amplitude, frequency)
- Altered sensing (over-/under sensing)
- Inhibition of stimulation (pause, asystole)
- Change in operational mode (incl. asynchronous stimulation)

*Ref: B Gauter-Fleckenstein et al., Strahlenther Onkol 2015; 191:393-404*

# Potential CIED errors by ionizing radiation

- Battery depletion (ERI-exchange indicator)
- Altered electrode sensing (impedance)
- Loss of telemetry or programming capabilities
- Reset in default setting (fallback mode)
- Loss of function

*Ref: B Gauer-Fleckenstein et al., Strahlenther Onkol 2015; 191:393-404*

## Other potential errors for ICD only

- Inhibition of antitachyarrhythmia therapy
- Altered (reduced) shock energy
- Prolonged detection and charging intervals
- Inadequate (shock) therapy

*Ref: B Gauter-Fleckenstein et al., Strahlenther Onkol 2015; 191:393-404*

# Potential CIED errors by EMI

- Altered sensing (over-/under sensing)
- Inhibition of stimulation (pause, asystole)
- Reed-switch interaction (asynchronous stimulation)
- Atrial-triggered fast ventricular pacing
- ICD: Inhibition of antitachyarrhythmia therapy
- ICD: Inadequate (shock) therapy
- Reset/reprogramming of device

*Ref: B Gauter-Fleckenstein et al., Strahlenther Onkol 2015; 191:393-404*

# Out-of-field radiation doses

- AAPM TG34 recommended  
“Pacemaker not in direct beam”
- AAPM TG158

*Ref: JR Marbach et al., AAPM Report No. 45, Med Phys 1994*

*Ref: SF Kry et al., AAPM TG158, Med Phys 2017; 44:e391-429*

# AAPM TG-34 recommendations

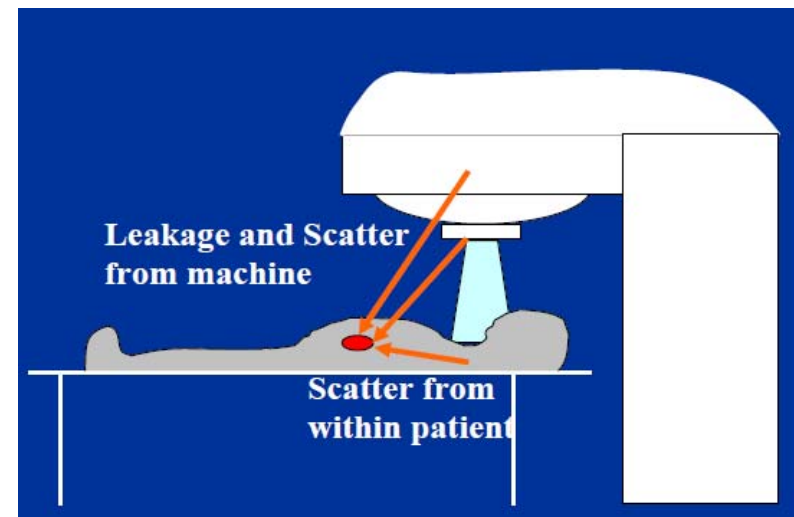
- Should not be treated with a betatron
- Should not be in direct radiation beam
- Dose should be estimated before RT
- If  $> 2$  Gy, should be checked prior to RT, and possibly at the start of each week
- Functional changes in pacemaker have been observed in the 2-10 Gy range

*Ref: JR Marbach et al., AAPM Report No. 45, Med Phys 1994*



# Out-of-field radiation doses

- Internal (patient) scatter  
Dominant in close proximity to the treated volume
- Collimator scatter
- Head leakage  
Dominant at distance  $> \sim 20$  cm



Ref: SF Kry et al., AAPM TG158,  
*Med Phys* 2017; 44:e391-429

Figure adapted from: (Last accessed on 9/4/19)  
<https://www.aapm.org/meetings/amos2/pdf/49-14482-90758-54.pdf>

# Out-of-field radiation doses

- Softer than primary beam energy
- Decrease with distance
- Increase with field size  
(when close to field edge)
- Increase with modulation due to more head leakage and collimator scatter  
(when farther from field)

*Ref: SF Kry et al., AAPM TG158, Med Phys 2017; 44:e391-429*

# Out-of-field radiation doses

- Beam energy  $> \sim 10$  MV  $\rightarrow$  Neutrons
  - Primary collimator, target, flattening filter, jaws, MLC...
  - Isotropic neutron emissions from accelerator head
  - Fluence of neutrons increases linearly with MU
  - For Varian accelerator:
    - $\sim 10$  times from 10 MV to 15 MV
    - $\sim 2$  times from 15 MV to 18 MV

*Ref: SF Kry et al., AAPM TG158, Med Phys 2017; 44:e391-429*

# Out-of-field radiation doses

- Decrease with Flattening filter-free (FFF)
- Increase with physical wedges
- Larger errors in dose calculation by treatment planning systems (TPS)  
when  $> 3$  cm from field edge or  $< 5\%$  isodose line
- Measurement and Monte Carlo Simulation

*Ref: SF Kry et al., AAPM TG158, Med Phys 2017; 44:e391-429*

# Published guidelines

- Cumulative dose
- Risk categories
- Clinical management

# Cumulative dose guidelines

- AAPM TG-34 (1994): 2 Gy limit
  - Does not include current technology and ICD
- Different among manufacturers and some do not provide a safe dose limit
- \*HRS consensus statement: < 5 Gy
- \*\*DSRO: Risk categories
- \*\*\*Upcoming AAPM TG-203: Risk categories

\*Ref: JH Indik et al., *Heart Rhythm* 2017; 14:e97-e153

\*\*Ref: CW Hurkmans et al. *Radiat Oncol* 2012; 7:198

\*\*\*Ref: D Mihailidis, <https://amos3.aapm.org/abstracts/pdf/87-22797-326454-102401.pdf>, Last accessed on 9/4/19

# Recommendations from Manufacturers

Recommendation	Biotronik	Boston Scientific	Medtronic	St. Jude Medical
Device checks	<b>Before</b> and <b>after</b> RT	Specific to patient Monitor <b>after</b> RT	<b>After</b> RT, If exceeds safe dose during RT	<b>During</b> and <b>after</b> RT
Max ICP dose	<b>2 Gy</b>	No safe dose	<b>5 Gy</b>	No safe dose
Max ICD dose	<b>2 Gy</b>	No safe dose	<b>1-5 Gy</b> dep. on model	No safe dose
Max energy	<b>&lt;10 MV</b>	Not stated	<b>≤10 MV</b>	Not stated
Inactivation of antitachycardia	Yes	Yes	Yes	Yes
Pb shielding	Yes	All available shielding options	No (ineffective against neutrons)	Not stated
Heart rhythm monitoring	Yes, during RT	Determine by physician team	Not stated	Yes

*Ref: T Zaremba et al., PACE 2015; 38:343-356*

# Risk categories – Dutch Society of Radiotherapy and Oncology

**Table 2 Patient risk categories: cumulative dose to the CIED and pacing independent versus pacing dependent**

	< 2 Gy	2-10 Gy	> 10 Gy
pacing-independent	Low risk	Medium risk	High risk
pacing dependent	Medium risk	Medium risk	High risk

Risk defined from the patients' perspective; how high is the risk for the patient? The patient's risk is not equal to the risk of a CIED defect.

*Upcoming TG-203\*\*\*: will adopt similar risk category approach but will likely define 2-5 Gy as medium risk and > 5 Gy as high risk*



# Pacemaker dependency

The risk of serious injury or death from pacemaker failure

	Class I	Class II	Class III
Symptoms	Bradycardia	Asymptomatic	Asymptomatic
Ventricular rate	No intrinsic activity	Ventricular rate <30 beats per minute	Ventricular rate > 30 beats per minute
Abrupt cessation of pacing	Fatal	Not fatal	Not fatal
Emergent/urgent situation	Expected	Not expected	Not expected
Level of cardiac monitoring	Intense and active, before, during and after radiotherapy: cardiac arrest team on call	Routine	Routine
Previous untoward cardiac history	Usually present	Not present	Not present
Pacemaker dependency	Highly dependent	Intermediately dependent	Non dependent

Ref: T Wadasadawala et al., Clin Oncol 2011; 23:79-85

# Guidelines by Dutch Society of Radiotherapy and Oncology

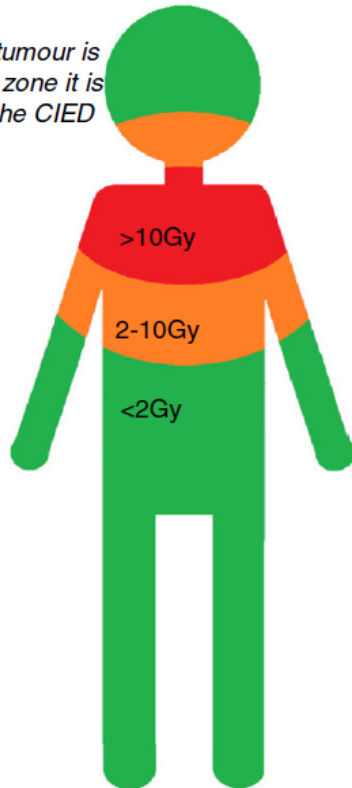
Patient with CIED and indicated radiotherapy

- Inform treating cardiologist and inform patient
- Determine patients' pacing-dependency
- If ICD, Inform if anti-tachycardia therapy can be switched of by magnet
- If CIED check-up > 3 months ago, plan check-up prior to start of radiotherapy

- Photon beam energy  $\leq 10\text{MV}$
- Estimate dose on CIED (seed rawing for indication)
- Minimize dose on CIED with treatment plan optimisation

# DSRO guidelines

When the tumour is within this zone it is likely that the CIED dose is\*:



## LOW RISK

- Audiovisual monitoring of patient
- In case ICD: program tachycardia therapy off or use magnet
- Letter to cardiologist
- ICDs: weekly check-ups

## INTERMEDIATE RISK

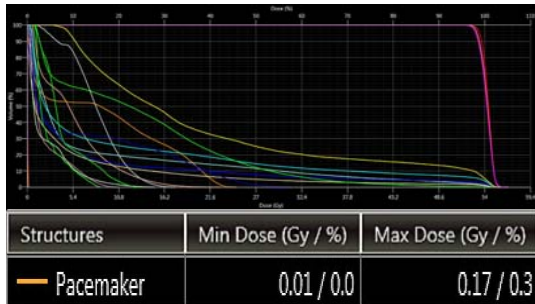
See LOW RISK plus:

- Crashcart present during RT
  - Weekly check-up CIED
  - Possibility of external pacing
  - Trained staff with cardiology expertise can be present within 10 minutes
- (if not, patients should be referred to another institute)

## HIGH RISK

- In exceptional cases a decision to start RT can be made
- safety measures which are at least those used for intermediate risk patients
- ECG-monitoring during every fraction
- CIED checked within 24 hours by pacemaker technician

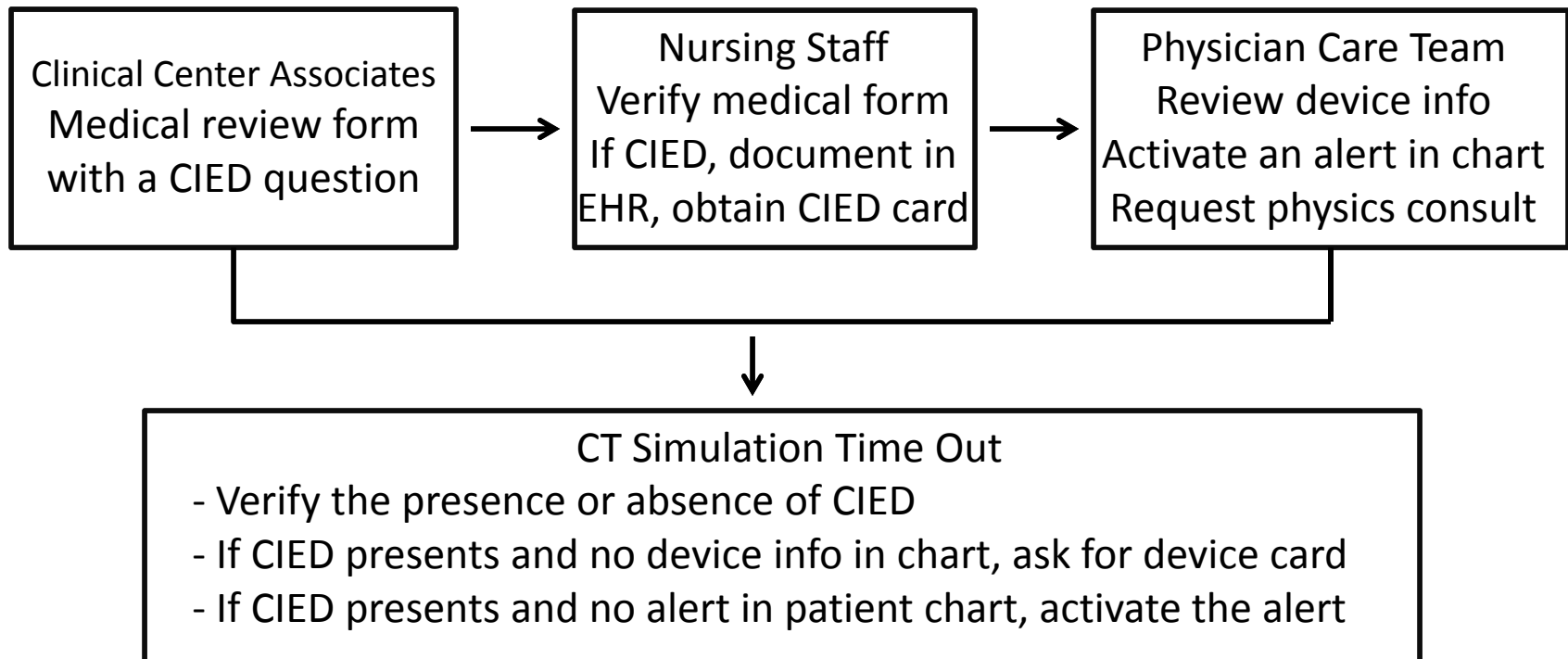
# Policy and Procedure



# CIED management P&P

- Identify patients who have CIED
- Alert and documentation in patient chart
- Multidisciplinary team clinical management
- Published guidelines and manufacture safe dose limit if provided

# Identify patients with CIED



# CIED document and Alert

Medical Device ID

Boston  
Scientific

**Patient:** Patient Name  
**Physician:** Following Physician/Clinic Name  
**Physician Telephone:** Following Phone

MFG	Product	Model/Serial	Implant Dt
Boston Sci	CRT-D	1234 968765	12-OCT-2015
Boston Sci	Lead	7654 123456	12-OCT-2015
Boston Sci	Lead	6789 234567	12-OCT-2015
Boston Sci	Lead	4321 345678	12-OCT-2015

## Implanted Cardiac Rhythm Management Patient

Contact physician for medical questions or emergency  
[www.bostonscientific.com](http://www.bostonscientific.com)

### For Patients

866.484.3268 (USA)  
001.651.582.4000 (Outside USA)  
[www.lifebeatonline.com](http://www.lifebeatonline.com)

For Security Personnel Magnetic security wands may adversely affect device's function. Do not place wand over device.

### For Medical Personnel

1.800.227.3422 or 651.582.4000

**MRI** – For questions regarding MRI device compatibility, see the Boston Scientific website at [www.bostonscientific.com/imageready](http://www.bostonscientific.com/imageready)

CRM-84301-AB...OCT2015

Patient Log and Chart Activity - ID: 007 Test, Word



Notifications:  
Pace Maker: ICD

OK

# Dosimetry procedure

- No primary radiation beam
- Photon beam energy  $\leq 10$  MV
- Contour CIED in CT images and report TPS computed maximum dose
- If no manufacture dose limit,  $<2$  Gy (TG34)
- If  $>2$  Gy, notify physicist and physician for further evaluation

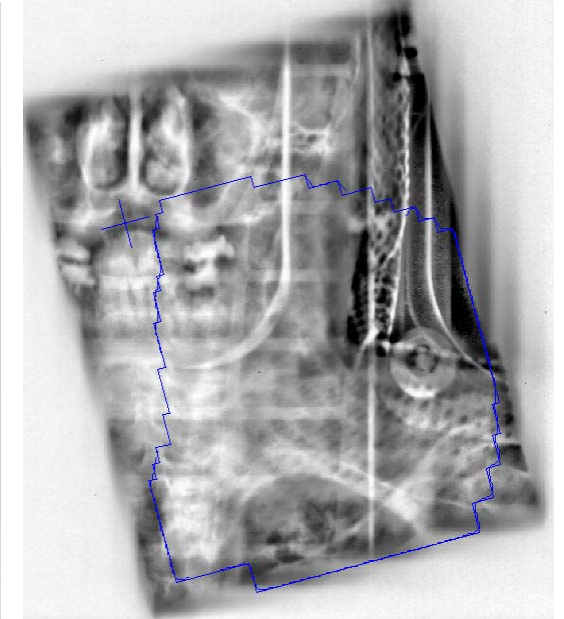
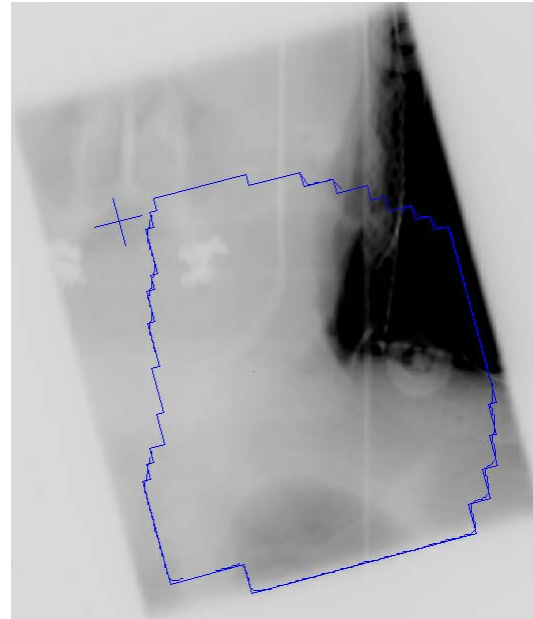
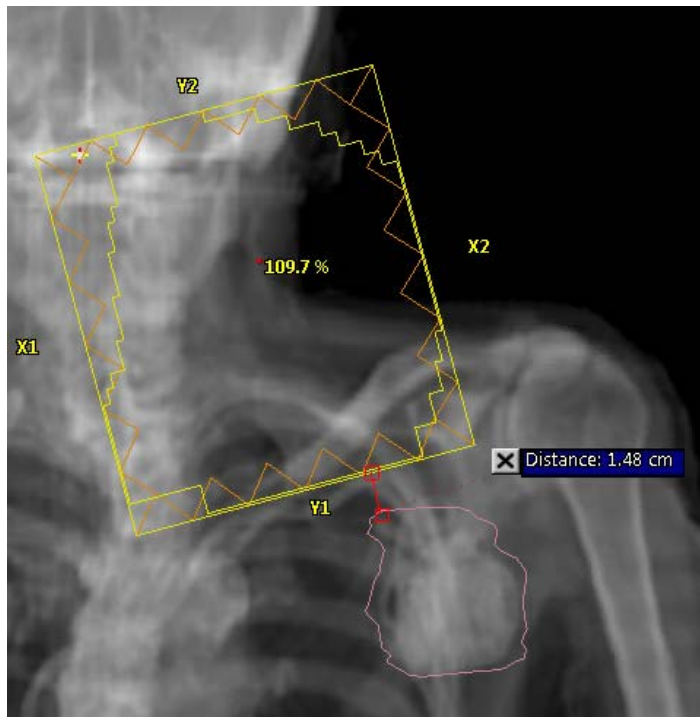


# Physicist procedure

- Review patient chart for CIED information
- Verify alert in patient chart
- Verify treatment plan and CIED doses according to guidelines and P&P
- Notify and discuss with relevant parties if problem detected

# Avoid direct beam at verification imaging

In this example, Y1 jaw was closed during double exposure MV imaging



# Physician and care team

- Schedule interrogation of the CIED by a manufacturer-representative. Frequency is at discretion of attending physician.
- Document interrogation report in EMR
- At least should interrogate CIED at completion
- If cumulative dose guidelines can not be met, make decision to choose other options, e.g. CIED relocation, magnet, etc.

# Summary

- Risk categories - cumulative dose limit, type of CIED and patient's CIED dependency
- Limitations in TPS out-of-field dose computation
- No direct radiation
- No high-energy photon
- Multidisciplinary clinical management -  
develop a **Standard Policy and Procedure!!!**

# CIED in radiation therapy

# Thank you!

