História radiačnej ochrany

Ing. Róbert Hinca PhD.

Objav X-lúčov 1895 Röntgenom

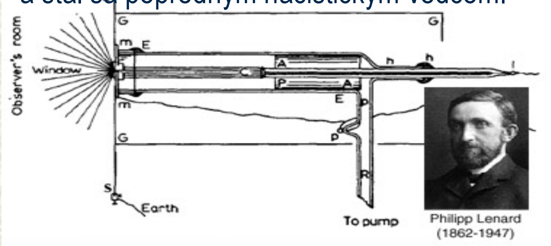
- Pred Röntgenom sa podobným javom venoval ***Wiliam Crookes*** (v roku 1880 ***nevenoval*** pozornosť sčerneniu fotografických platní vplyvom katódového žiarenia)
- ***Philipp Lenard (*1862 v Bratislave, †1947)*** v roku 1893 pozoroval fluorescenciu kryštálov v blízkosti katódy (nepokračoval vo výskume, lebo dostal miesto profesora vo Vroclave a odišiel z Bonnu). Lenard upravil Crookesovu trubicu tak, že skonštruoval malé okienko (Al) cez ktoré sa katódové žiarenie dalo lepšie skúmať. Lenard dostal v 1905 nobelovu cenu aj za príspevok k objavu elektrónu **Thompsonom** v roku 1897.
- Snažili sa dokázať existenciu vysokofrekvenčného elektromagnetického žiarenia predpovedaného *Hermann von* ***Helmholtzom***, u ktorého študoval *Heinrich* ***Hertz***, u ktorého študoval ***Lenard***.

Philipp Lenard (*1862 v Bratislave, †1947)

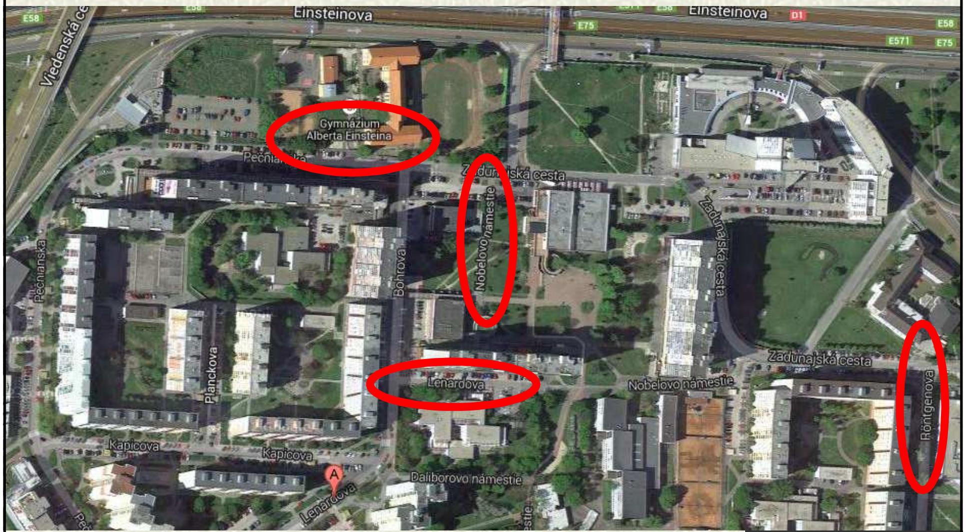
- Lenard was born in Pressburg, Hungary (now part of Slovakia). Otec bol tirolský obchodník s vínom.
- V čase štúdií na gymnáziu v Bratislave skúmal spolu so svojím profesorom fyziky Virgilom Klattom (1850– 1935) fosforescenciu. Po maturite na reálke v Bratislave (1880) študoval fyziku na univerzitách v Budapešti, Viedni, Berlíne a Heidelbergu. Potom prešiel do Bonnu k **Hertzovi** a v roku 1892 sa tu habilitoval.
- Medzi prvými skúmal prechod katódových lúčov cez tenké kovové doštičky. Na tento účel skonštruoval špeciálnu katódovú trubicu s malým otvorom (tzv. Lenardovo okienko), čo umožnilo nielen preskúmať vlastnosti katódových lúčov, ale tiež odseparovať elektróny a stanoviť ich hmotnosť. Jedno zo svojich „okienok" zapožičal aj **W. C. Röntgenovi**, čím nepriamo prispel k objavu lúčov X (Röntgenového žiarenia).

*Philipp Lenard (*1862 v Bratislave, †1947)*

- Počas spolupráce s H. Hertzom sa začal zaoberať fotoelektrickým javom. Dokázal, že pri vonkajšom fotoefekte sa uvoľňujú elektróny (1899) a stanovil zákonitosti fotoelektrického javu (1902): energia vyletujúcich fotoelektrónov nezávisí od intenzity dopadajúceho svetla a je priamo úmerná jeho frekvencii. Tieto fakty boli v rozpore s klasickou fyzikou a vysvetlil ich až **Albert Einstein** na základe svojej hypotézy, že svetlo musíme pokladať za prúd kvánt energie.
- Od 20-tych rokov sa angažoval ako člen NSDAP a stal sa popredným nacistickým vedcom.

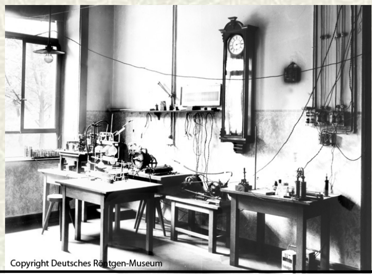


Gymnázium Alberta Einsteina je blízko Lenárdovej ulice v Petržalke



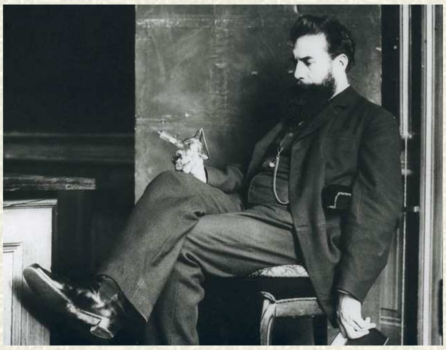
WILHELM CONRAD RÖNTGEN

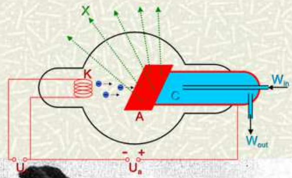
- **Elektrotechnik -** na **štúdium katódových lúčov** používal **vákuovú trubicu - Hittorf-Crookes tube**.
- 8. novembra 1895, na Univerzite vo Würzburgu, si Wilhelm Röntgen všimol **záblesky fluorescenčnej tabuľky**.
- Röntgen okamžite usúdil, že fluorescencia bola spôsobená neviditeľným žiarením z Crookesovej trubice, ktoré preniklo cez nepriehľadný čierny papier, do ktorej bola trubica zahalená.
- **Röntgen objavil lúče X (X-rays).**

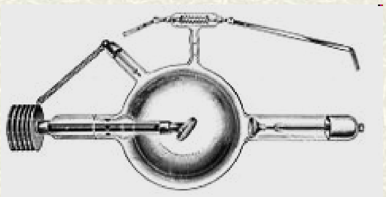


Povestný prvý snímok vyhotovený Röntgenom 22. Decembra 1895, a odoslaný fyzikovi Franzovi Exnerovi do Viedne.

WILHELM CONRAD RÖNTGEN a prvé prístroje pre fluoroskopiu (Edison)





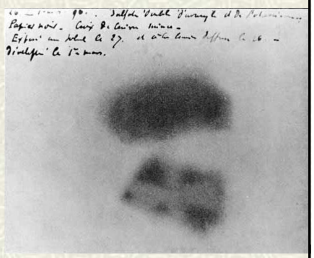


WILHELM CONRAD RÖNTGEN

- However, prior to his first formal correspondence to the University Physical-Medical Society, Röntgen spent two months thoroughly investigating the properties of X rays. Silvanus Thompson complained that Röntgen left "little for others to do beyond elaborating his work." For his discovery, **Röntgen received the first Nobel Prize in physics in 1901**.
- When later asked what his thoughts were at the moment of his discovery, he replied "I didn't think, I investigated." It was the crowning achievement in a career beset by more than its share of difficulties. As a student in Holland, Röntgen was expelled from the Utrecht Technical School for a prank committed by another student.
- Even after receiving a doctorate, his lack of a diploma initially prevented him from obtaining a position at the University of Würzburg. He even was accused of having stolen the discovery of X rays by those who failed to observe them. Nevertheless, Röntgen was a brilliant experimentalist who never sought honors or financial profit for his research. He rejected a title (i.e., von Röntgen) that would have provided entry into the German nobility, and donated the money he received from the Nobel Prize to his University.
- Röntgen did accept the honorary degree of Doctor of Medicine offered to him by the medical faculty of his own University of Würzburg. However, he refused to take out any patents in order that the world could freely benefit from his work. At the time of his death, Röntgen was nearly bankrupt from the inflation that followed WW I.

ANTOINE HENRI BECQUEREL

- **Henri Becquerel** sa narodil v rodine vedca.
- Už jeho starý otec robil elektrochemické pokusy a jeho otec skúmal javy **fluorescencie and fosforescencie**.
- **Becquerel objavil v roku 1896 radioaktivitu**, spontánnu emissiu žiarenia látkou.
- Najprv bol presvedčený, že fluorescenčný materiál uchováva slnečnú energiu a potom ju vyžaruje.
- Po Röntgenovom objave sa snažil dokázať, že soli uránu sú zdrojom X-lúčov.
- Keď raz bolo v Paríži zamračené, prerušil svoje pokusy a schoval materiál do šuplíka. Keď ho však po čase vyvolal, tak získal ostrý a jasný obrázok aj bez slnka.
- Becquerel urobil správny záver, že materiál vyžaruje spontánne bez vonkajšieho zdroja energie.
- **V roku 1903 dostal Nobelovu cenu za fyziku spolu s manželmi Curie.**



ANTOINE HENRI BECQUEREL

- And so, upon learning how Wilhelm Röntgen discovered X rays by observing the fluorescence they produced, Becquerel had a ready source of **fluorescent materials** with which to pursue his own **investigations of these mysterious rays.**
- The material Becquerel chose to work with was a **double sulfate of uranium** and potassium which he exposed to sunlight and placed on photographic plates wrapped in black paper. When developed, the plates revealed an image of the uranium crystals. Becquerel concluded "that the phosphorescent substance in question emits radiation which penetrates paper opaque to light." **Initially he believed that the sun's energy was being absorbed by the uranium which then emitted X rays.**
- Further investigation, on the 26th and 27 of February, was delayed because **the skies over Paris were overcast** and the uranium-covered plates Becquerel intended to expose to the sun were returned to a drawer. On the first of March, he developed the photographic plates expecting only faint images to appear. **To his surprise, the images were clear and strong.**
- This meant that the **uranium emitted radiation without an external source of energy** such as the sun. **Becquerel had discovered radioactivity, the spontaneous emission of radiation by a material.** Later, Becquerel demonstrated that the radiation emitted by uranium shared certain characteristics with X rays but, unlike X rays, could be deflected by a magnetic field and therefore must consist of charged particles. For his discovery of radioactivity, **Becquerel was awarded the 1903 Nobel Prize for physics.**

PIERRE & MARIE CURIE

- Skôr ako **Pierre Curie** stretol **Mariu Sklodowsku** mal už veľkú reputáciu v oblasti elektriny a magnetizmu. V roku 1880 spolu s bratom Jacquesom objavili **piezoelektrický** jav – keď tlak na kryštál spôsobí vznik elektrického potenciálu.
- Významný výskum urobil v oblasti magnetizmu, keď identifikoval teplotu nad ktorou materiál stráca magnetické vlastnosti – tzv. **curieho teplotu**.
- Napriek tomu Pierre krátko po svatbe s Mariou podriadil svoj výskum záujmom svojej manželky. Spolu začali výskum nového javu – rádioaktivity na uránovej rude.
- Aj keď objav rádioaktivity patrí Henri Becquerelovi, termín rádioaktivita prvýkrát použila Mária.

PIERRE & MARIE CURIE

Po chemickej **extrakcii uránu** z rudy Mária zaznamenala, zvyšok je aktívnejší ako čistý urán. Vtedy usúdila, že ruda obsahuje nové prvky, ktoré sú tiež rádioaktívne. To viedlo k objavu prvkov ***polonium* a *radium***, ale znamenalo to 4 roky mravčej práce pri spracovaní ton uránovej rudy, aby získali dostatočné množstvo každého prvku na určenie chemických vlastností.

Za prácu v oblasti **rádioaktivity** **manželia Curie získali Nobelovu cenu za fyziku roku 1903**. O tri roky neskôr Pierre tragicky zahynul pod kolesami koča a jeho učiteľské miesto na Sorbonne dostala Maria ako prvá žena v 650 ročnej histórii univerzity. Na jeho počesť v roku 1910 Rádiologický kongres navrhol pomenovať základnú jednotku rádioaktivity – curie ako množstvo jadier radónu v rovnováhe s jedným gramom rádia (neskôr jednoducho 1Ci = 3.7 x 10^{10} dps).

V roku 1911 **Marie získala Nobelovu cenu za chémiu** za objav **rádia a polónia**.

Zvyšok života venovala výskumu terapie nádorov rádiom. Mária Curie zomrela č. júna 1934 na následky anémie **(typ rakoviny krvi)** spôsobenej bezpochyby ionizujúcim žiarením.

Výskum jadra a jadrovej energie

- **Rutherford** - objav protónu, zavedenie termínov alfa, beta, gama žiarenie (Paul **Villard**),
- **Chadwick** - 1932 objav neutrónu
- Irene a Frederic Joliot **Curie** - 1934 štiepenie neutrónmi, umelá rádioaktivita
- **Hahn, Strassmann, (Meitner, Frisch)** – štiepenie uránu
- **Bohr, Bethe, Fermi, Oppenheimer, Szilard, Teller, Chariton,Kurčatov, Sacharov . . .**

História radiačnej ochrany

1895	8. november - objav lúčov X	W.K. Roentgen
1896	3. január - zverejnenie objavu X - lúčov	
	február - Objav rádioaktivity	H. Becquerel
	3. marec - Prvá správa o možnom poškodení očí X lúčmi	T.A. Edison, W.J. Morton
	10. apríl - zaznamenaný prípad epilácie po ožiarení X lúčmi	J. Daniel
	18. apríl - zaznamenané sčervenanie pokožky po ožiarení	L. G. Stevens
	júl - prvé ochranné opatrenie - ťažká sklenená platňa na ochranu očí počas rádiografie	W.H. Rollins
	Správa o poškodení zdravia (popáleniny pokožky)	H.D. Hawks
	18. november - Sčervenanie pokožky vyvolané ožiarením	E. Thomson
	Pozlátený elektroskop bol použitý na meranie žiarenia	L. Benoist
	použitie X-lúčov v lekárskej diagnostike, stomatológii a terapii (prsníka)	Frost, Kells, Rollins ...

Prvé zásady ochrany

- **r. 1896** – rok po objavení X-lúčov americký inžinier Wolfram Fuchs sformuloval prvé rady na ochranu:
  - čas ožiarenia skrátiť na minimum,
  - dodržovať odstup od rentgenky aspoň 30 cm a
  - natrieť si pokožku vazelínou.
- V podstate sformuloval tri hlavné zásady ochrany pred vonkajším ožiarením: **čas, vzdialenosť a tienenie**.

História radiačnej ochrany

1898	Január - Na ochranu pred žiarením použitý hliníkový filter	E. Thomson
	Júl - Olovené kryty a kolimátory použité pre RTG trubice	W.H. Rollins
	Júl - Prvýkrát použitý termín rádioaktivita	P. & M. Curie
	December - Objavené Rádium	P. & M. Curie
	Objavenie gama žiarenia	P. Villard
1899	Apríl - Návrh na licencovanie rádiografických činností	J. Dennis
	Zverejnenie ochranných pomôcok v RTG. katalógu (rukavice, zástery...)	R. Friedlander Co.
1900	Odporúčanie zvýšiť vzdialenosť na zníženie ožiarenia kože	M.K. Kassabian
1901	3. január - vyslovený predpoklad o smrteľnosti vysokých dávok žiarenia	
	Erytém kože v dôsledku terapie rádiom	H. Becquerel

História radiačnej ochrany

1902	Experimentálne preukázanie smrteľnosti žiarenia na vyššie formy života	W.H. Rollins
1903	Prvé zariadenie na priame pozorovanie žiarenia; spinthariscope	W. Crookes
1904	Október - Smrť priekopníka RTG. techniky v dôsledku vysokého kumulatívneho ožiarenia	C.M. Dally
1905	Navrhnutá jednotka merania ožiarenia odvodená od ionizácie prostredia	M. Franklin
1906	Zvrejnený zákon rádiosenzivity orgánov	J. Bergonie & R. Tribondeau
1907	Preukázané mutácie na ropuchách v dôsledku ožiarenia X lúčmi	C.R. Bardeen
	Fotografická platňa nosená vo vrecku použitá na meranie ožiarenia	R.V. Wagner
	Použitie plynom plnených trubíc na detekciu žiarenia	E. Rutherford
1912	Zavedený medzinárodný rádiový štandard a jednotka Curie	M. Curie
1913	Vylepšená RTG trubica žhavená katóda a wolfrámový terčík dovoľujú zvýšiť použité napätie	W.D. Coolidge
1915	**Britská Rentgenologická spoločnosť zverejnila prvé odporúčania pre radiačnú ochranu**	

Zákon rádiosenzivity: Na žiarenie X sú senzitívnejšie bunky, ktoré vykazujú vyššiu reprodukčnú aktivitu.

Obete prvých výskumov

Clarence Dally (1865-1904)

– asistent u Edisona, zaoberal sa prístrojom na X-ray snímkovanie, dostal veľké dávky na tvár a ruky, lebo pridržiaval snímkované predmety pred RTG lampou. Postupne sa objavili pľuzgiere, nekrózy, epilácia, nasledovali amputácie a smrť. „The strangest part of all," lamented Edison, „Is that all this is the result of work with the X-ray five or six years ago and now comes this result"

Mihran Kassabian (1870-1910)

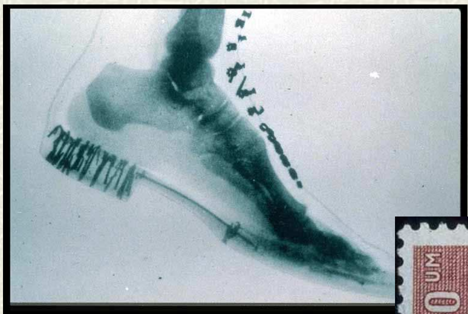
úzkostlivo zaznamenal a vyfotografoval svoje ruky postihnuté rozsiahlou nekrózou a sériou amputácií v nádeji že po svojej smrti pomôže svojim nasledovníkom uchrániť si zdravie.

Pomník priekopníkom RTG techniky

By the early 1900's amputated limbs became the unofficial badge of the x-ray worker. One meeting of a Roentgen Society was marred by an embarrassing mistake. At dinner, roast chicken was served but not one member among them had a second arm in which to use their knife.

Priekopníkom röntgenovej techniky, ktorí trpeli na následky ožiarenia poprípade na následky zomreli, odhalili pomník v roku 1936 v Hamburgu. Na pomníku bolo 169 mien z 15 krajín.

X-ray euphoria



Foot in high-button shoe, radiograph made in Boston by Francis Williams in March 1896. Typical of early images reproduced in the popular press.

1977 Mauritania (northwestern Africa) stamp portrays the bones of a hand and wrist as they would be viewed using the X-ray. This stamp was one of many which commemorated 1977 as World Rheumatism year.

Eufória z nových objavov

MAY 8 1904

RADIUM AND X-RAY USED TO BEAUTIFY

Birthmarks Bleached Out by the Combined Power, and Other Blemishes of This Nature Also Said to Be Safely Removed.

MEN BENEFIT BY THE RECENT DISCOVERIES

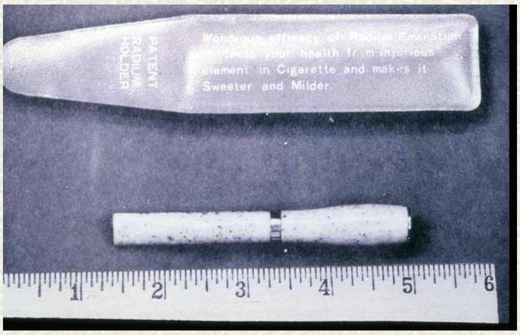
BEAUTIFYING X-RAYS. Propaganda claiming the beautifying effects of X-ray radiation caught the attention of many women in the early twentieth-century.

Eufória z nových objavov

The public wanted radiation in everything, and business was happy to satisfy the craving. You could buy Agua Radium, ready to drink.

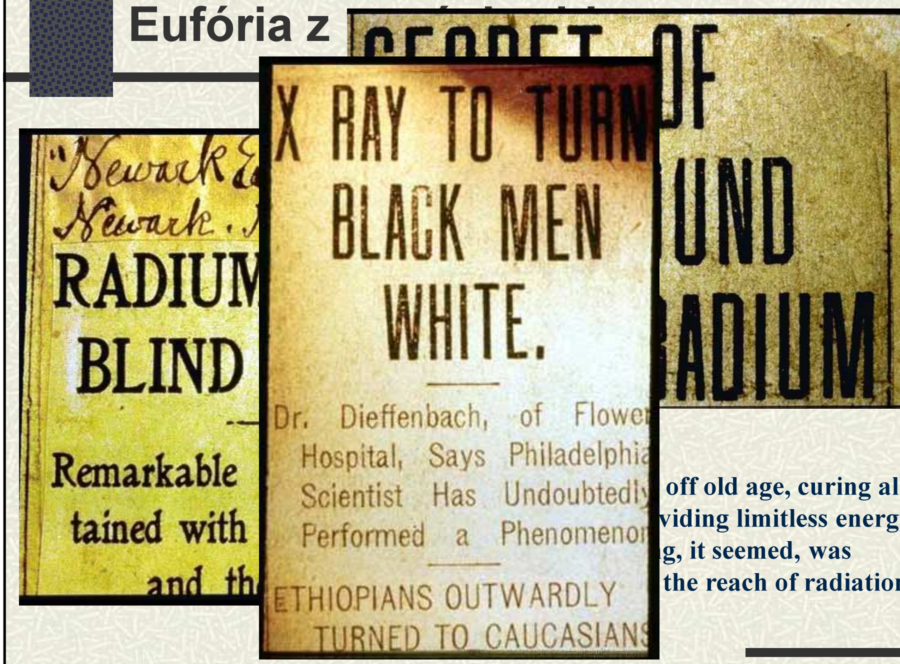
Glowing radium flourescent cocktails were all the rage on the banquet circuit.

Eufória z nových objavov



LIFESTONE RADIUM CIGARETTE HOLDER. Advertised as protecting the user from lung cancer.

Eufória z



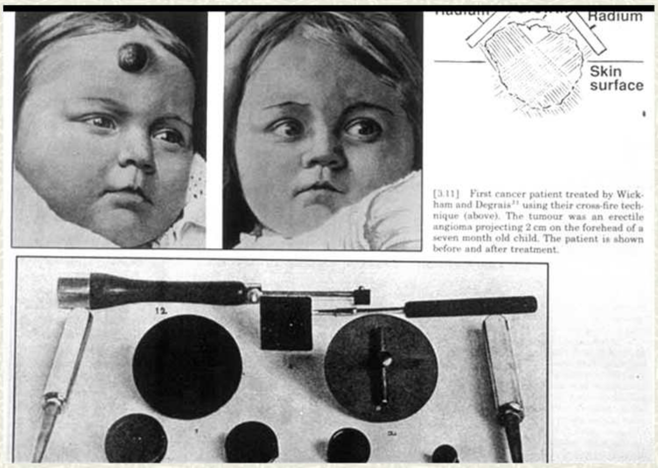
off old age, curing all
viding limitless energy -
g, it seemed, was
the reach of radiation.

Early radium treatment

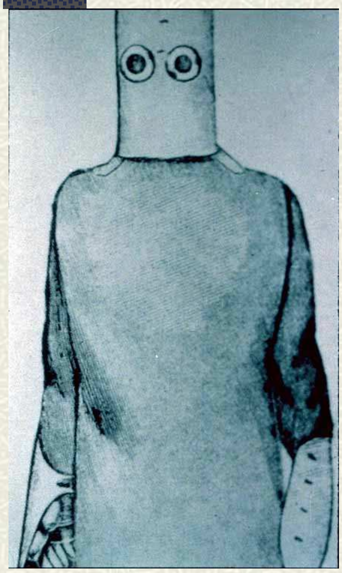
The painstaking process of extracting minute amounts of radium from tons of ore made the element extraordinarily rare and expensive in these earliest years.

The Curies loaned small amounts to various Paris physicians, including Louis Wickham and Paul Desgrais who in 1907 treated this child's erectile angioma using a crossfire technique.

Below, early applicators were devised in a number of shapes and sizes-flat for surface work and cylindrical for intracavitary use.



Ochranné prostriedky



Historické návrhy ochranných prostriedkov:

– olovené sklá,

– ťažké odevy,

– kovové helmy a

– kovové chrániče

neuľahčovali už aj tak zložitú prácu rádiológov.

Aféra Radium Girls

- Väčšina používaných **ručičiek a ciferníkov** býva luminiscenčná či fluorescenčná. Niektoré bývajú natrené relatívne neškodným fosforom, sírnikom zinku, či oxidmi hliníka s rôznymi prímesmi. Vydržia ale svietiť väčšinou len niekoľko desiatok minút po osvetlení.
- Časť výrobcov využíva či využívala trochu drastickejšie metódy – hodinové ručičky natrené rádioaktívnymi farbami s prímesou **rádia** či **tricia** (používal ich aj český výrobca Prim).

Radium girls

- Spoločnosť U. S. Radium v americkom štáte New Jersey sa v rokoch **1917-1926** zaoberala získavaním a čistením **rádia** z karnotitu, čo je okrem smolinca najznámejšia ruda rádia a uránu.
- Cieľom bola **produkcia luminiscenčných farieb**.
- Jedným z najvýznamnejších obchodných partnerov tejto spoločnosti bola americká armáda, ktorej U. S. Radium dodávala **rádioluminiscenčné hodinky.** Tento kontrakt umožnil spoločnosti U. S. Radium zamestnať asi **70 pracovníčok, ktoré nanášali rádioaktívne farby** na hodinové ciferníky.

Radium Girls pri práci

Už vtedy sa vedelo, že zvýšená rádioaktivita je pre ľudský organizmus nebezpečná, a preto byli výskumní a technickí pracovníci chránení. Žiadna ochrana sa ale nevzťahovala na robotníčky, ktoré nanášali hotovú farbu na ciferníky.

Radium Girls

Robotníčky boli naviac uistené, že rádium je úplne bezpečné. Evidentne tomu verili, lebo mnohé z nich si rádioaktívnou farbou **maľovali aj nechty, zuby** alebo si ich dokonca nanášali na telo. Na maškarných plesoch potom doslova žiarili.

Ďalším zvykom, ktorý sa im vypomstil, bolo **olizovanie špičiek štetcov**, ktorými maľovali ciferníky. Olizovaním zaostrovali rozstrapkané špičky štetcov pre presnejšie maľovanie.

Malé množstvo farby pritom často prehltli, čo je to najhoršie, čo sa môže s rádioaktívnym materiálom stať.

Radium Girls ochoreli

Potom, čo väčšina robotníc ochorela, vzniklo podozrenie, že za ich problémami je práve dlhodobý kontakt s rádioaktívnou farbou. Medzi hlavné problémy patrila **nekróza čeľusti, vypadávanie zubov, zlomeniny, problémy s krvotvorbou** a celý rad ďalších problémov dnes bežne spájaných s rádioaktivitou.

Najväčšie škody dokáže rádium napáchať na našich **kostiach**, pretože telo s ním zachádza podobne ako s **vápnikom**.

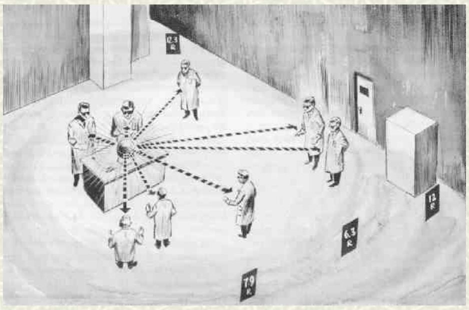
Niektoré z pracovníc spoločnosti U. S. Radium v sebe mali toľko rádioaktivity, že sa ich čeľuste zobrazovali na röntgenologickom filme aj bez použitia röntgenového žiarenia.

Súdny spor a Marie Curie-Skłodowska

Spoločnosť v reakcii na zdravotné problémy nechala pracovníčky vyšetriť a zistila, že ich telá obsahujú vysoké dávky rádioaktivity. Túto skutočnosť im však zamlčala.

O súdnom spore s U. S. Radium sa dopočula aj Marie Curie-Skłodowska. V roku 1928 napísala: „Nie som lekár, takže nemôžem s istotou posúdiť, či dievčatá z New Jersey zomrú. Ale na základe novinových správ o metódach ich práce si myslím, že metódy zachádzania s rádiom je potrebné zmeniť.“

Tickling The Dragon's Tail
- critical assembly experiment



On May 21, 1946, the screwdriver slipped, the upper beryllium hemisphere fell and caused a "prompt critical" reaction, resulting in a burst of hard radiation. The "blue glow" of air ionization was observed and a "heat wave" was felt by the scientists in the room. Slotin instinctively jerked his left hand upward, lifting the upper beryllium hemisphere and dropping it to the floor. He exposed himself to a lethal dose (around 2100 rems, or 21 Sv) of neutron and gamma radiation, in history's second criticality accident.
Louis Slotin died nine days after accident.

História radiačnej ochrany

1921	British X-Ray and Radium Protection Committee vydáva memorandum, prvá norma pre ochranu pred X lúčmi	
1922	American Roentgen Ray Society si osvojila princípy ochrany pre X lúčmi	
	Použitý fotografický film na osobné monitorovanie	**G. Pfahler**
1925	Navrhnutá "tolerance dose" (dovolená dávka)	**A. Mutscheller**
Založenie International Commission on Radiological Units (ICRU).		
1927	Genetické efekty ožiarenia x-lúčmi preukázané	**H.J. Muller**
	Prva komerčná ionizačná komora vyrobená v USA	**J. Victoreen**
1928	Jednotka Rentgen formálne prijatá	
Založenie International X-Ray and Radium Protection Committee (ICRP)		
1929	Prvý prenosný monitor žiarenia	**L.S. Taylor**
1931	**USACXRP zverejňuje prve odporúčanie - 0,2 R/day**	
1932	Zverejnená koncepcia vyššej prípustnej dávky pri parciálnom ožiarení tela (ruka...)	**G. Failla**
	Objav neutrónu	**E. Chadwick**
1934	**ICXRP odporúča maximálnu dovolenú dávku 0,2 R/day**	
1935	Sformulovaný princíp Bragga-Graya o ionizácii prostredia	**L.H. Gray**
1936	USACXRP odporúča znížiť maximálnu dovolenú dávku na 0,1 R/day	
1941	Suggested maximum permissible dose of 0.02 R/day	**L.S. Taylor**

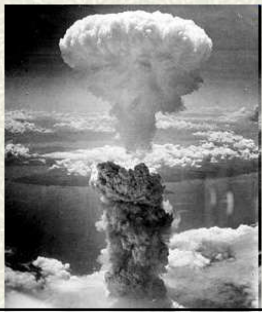
1R = 8,7 mGy vo vzduchu

História radiačnej ochrany

- **r. 1931** - NCRP (Národný výbor pre radiačnú ochranu v USA) schválil jednotku expozície "röntgen" (R)
- **r. 1934** – NCRP navrhol stanoviť hornú prahovú hranicu externého ožiarenia na 0,2 R/deň (to zodpovedá limitu na úrovni okolo 500 mSv/rok)
- Predpokladalo sa, že hodnoty expozície pod prahovou hodnotou nespôsobujú nebezpečie
- Limit v praxi znamenal, že pracovník musel dodržiavať určitú vzdialenosť od žiariča a súčasne dobu práce, aby nedošlo k jeho prekročeniu
- ***Vzdialenosť*** a ***čas*** boli a sú najjednoduchšími spôsobmi ochrany pred ožiarením z externých zdrojov žiarenia

Hirošima a Nagasaki

- **6 august 1945 bez akéhokoľvek varovania americký bombardér ENOLA GAY zhodil jadrovú bombu LITTLE BOY na Hirošimu.**
- **Explózia úplne zničila viac ako 10 km^2 centralnej časti mesta.**
- **90 000 ľudí bolo usmrtených okamžite, 40 000 zranených, veľa z nich na následky ožiarenia zomrelo v najbližších dňoch**
- **3 dni potom druhá jadrová bomba FAT MAN usmrtila v Nagasaki 37 000 ľudí a zranila 43 000.**



Následky atómového bombardovania

- Prvé dva-štyri mesiace zomrelo na akútne následky bombardovania 90 000–166 000 ľudí v Hirošime a 60 000–80 000 v Nagasaki
- Odhady hovoria, že 60% zhorelo priamo výbuchom alebo od požiarov, 30% pádu trosiek a 10% od iných príčin.
- Oneskorené úmrtia boli spôsobené popáleninami, ožiarením, a iné poranenia spolu s inými ochoreniami.
- Celkovo okamžite alebo v krátkom čase po bombardovaní zomrelo na chorobu z ožiarenia 15–20%, 20–30% zhorelo pri výbuchu a 50–60% z iných príčin. Iné príčiny následkom ožiarenia sú leukémia (231 preukázaných úmrtí), zhubné nádory (334 preukázaných úmrtí)
- Spolu sa udáva 200 000 prevažne civilných obetí.

História radiačnej ochrany

- **r. 1946** - NCRP upúšťa od prahovej koncepcie, ktorá sa používala pred 2. svetovou vojnou.
- Široké používanie rádioaktívnych látok (najmä v súvislosti s vývojom jadrovej zbrane) počas vojny vzbudilo určité znepokojenie, ktoré viedlo ku vzniku nových doporučení v súvislosti s ochranou pred žiarením.
- Ku koncu vojny skupina výskumníkov, vrátane NCRP, ktorí sa zaoberali otázkami ochrany pred žiarením, sa priklonila k "**bezprahovej**" koncepcii, podľa ktorej neexistuje absolútne bezpečná dávka.
- Zdalo sa rozumným predpokladať, že akékoľvek, i malé množstvo žiarenia, môže spôsobiť poškodenie, najmä však reprodukčných orgánov.

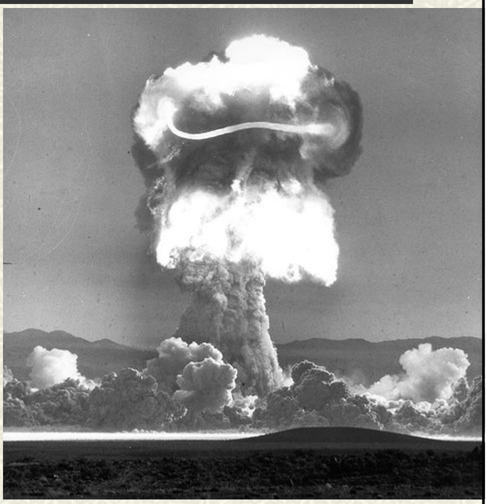
História radiačnej ochrany

- **r. 1949** - Na konci 40-tych rokov vznikla potreba rozpracovať pravidlá radiačnej ochrany aj pre obyvateľstvo.
- Bol prijatý pojem "RBÚ" (relatívna biologická účinnosť jednotlivých druhov žiarenia, dnes QF - faktor kvality, radiačný váhový faktor w_R), a bola zavedená jednotka ekvivalentnej dávky rem (rem=10^{-2}Sv).

História radiačnej ochrany

- r. 1949 ICRP vyslovila nasledovné požiadavky:
  - Znížiť najvyššiu dovolenú dávku o 50%, t.j. na hodnotu 50 mrem/deň (0,5 mSv/deň).
  - Pri ožiarení považovať za kritický orgán krvotvorné orgány a stanoviť pre ne najvyššiu prípustnú dávku vo výške 300 mrem/týždeň (3 mSv/týždeň).
  - Doporučiť tieto hodnoty koeficientov RBÚ:
    - Pre röntgenovské, γ a β lúče RBÚ=1,
    - pre tepelné neutróny RBÚ=5,
    - pre rýchle neutróny a častice α RBÚ=10.

Miss Atomic Bomb of 1957



37 kt „Priscilla“ na NTS cca 100km od Las Vegas, Pri testovaní rozmiestnili v okolí 719 prasiat.

TESTING THE TROOPS

V rokoch 1945-1962 USA a ZSSR robili atmosférické testy jadrových zbraní, ktorých sa zúčastňovali armádne jednotky.

Vojaci na zamorenom území robili manévre krátko po výbuchu, alebo počas cvičenia bola v rajóne zhodená atómová bomba.

"We were nothing more than guinea pigs"

V Rusku napr. gen. Žukov požadoval precvičiť činnosť vojsk počas výbuchu A bomby, tak v roku 14.09.1954 počas cvičenia 40000 vojakov odpálili 40 kT bombu na polygóne Totsk (Ural).

Napr. Nevada Test Site:

1957 Plumbbob – 18 000 vojakov

1958 Hartack – 20 000 vojakov

1962 Nougat – 31 000 vojakov

V USA sa v sedemdesiatych rokoch začali procesy veteránov z týchto pokusov, ktorí boli ožiarení počas manévrov.

V Rusku sa až v 90-tych rokoch veteráni, ktorí prežili manévre dovolali kompenzácií.

ALAPA

- **r. 1954** - Prijatie koncepcie **"ALAPA"** (As Low as Practically Achievable - Tak nízko, ako je to prakticky dosažiteľné) zamenilo doteraz používané **„lowest possible“.**
- ICRP prehlásilo tézu, že **neexistuje absolútne bezpečná úroveň** ožiarenia nad prírodným pozadím a preto pri činnostiach treba zvoliť praktickú úroveň, ktorá z pohľadu súčasných vedomostí predstavuje zanedbatalné riziko.
- Napriek takémuto prístupu neboli zrušené prahové úrovne stochastických efektov. Komisia navrhla využívať v radiačnej ochrane veličinu absorbovaná dávka a jednotku rad (=0,01 Gy) spolu s RBÚ váhovanou jednotkou rem (=0,01Sv).

História radiačnej ochrany

- **r. 1958** - Nazhromaždené experimentálne údaje o nízkoaktívnom žiarení k tomuto roku viedli ICRP **k ďalšiemu znižovaniu dávok a to na 100 mrem/týždeň (1 mSv/týždeň),** avšak kvôli väčšej pružnosti pri používaní týchto pravidiel bolo dovolené absolvovať do 3 rem (30 mSv) počas ľubovoľného štvrťroka v danom roku za podmienky, že celková ročná dávka nepresiahne hodnotu 5 rem (50 mSv).
- Taktiež bola stanovená kumulovaná dávka k danému veku, ako aj veľkosť expozície jednotlivých orgánov ľudského organizmu.
- Z odporúčaní ICRP 1958 vychádzala Vyhláška MZ SR č.65/1972 (analogická k vyhláške MZ ČR č. 59/1972) a jej platnosť bola zrušená až vyhláškou MZ SR č. 12/2001.

Lineárna bezprahová koncepcia

- **r. 1966** – ICRP vydala Publikáciu 9 v ktorej sa už naplno implementovala lineárna bezprahová koncepcia vzťahu dávky a účinku.
- V radiačnej ochrane sa odporúčal využívať princíp optimalizácie. Optimálna ochrana mala byť dôsledkom analýzy nákladov a prínosov (cost benefit).

História radiačnej ochrany

- **r. 1977** - ICRP vydala doporučenie č. 26, ktoré zásadne ovplyvnili radiačnú ochranu.
- Zavedené pravidlá sa považujú za moderný prístup k radiačnej ochrane.
- K systému ***limitovania*** dávok bola pripojená požiadavka ***optimalizácie*** a ***odôvodniteľnosti*** v radiačnej ochrane.

História radiačnej ochrany

- **r. 1990** - ICRP vydala doporučenie č. 60, ktorými sa zmenili prístupy k radiačnej ochrane a sprísnili limity a prístupy k hodnoteniu ožiarenia.
- Zavádza sa nové ponímanie zdravotného poškodenia ako miery radiačného poškodenia zahrňujúcu rakovinu vedúcu k úmrtiu (fatálna rakovina), dedičné poškodenie, ale aj rakovinu nevedúcu k úmrtiu (nefatálna rakovina).

História radiačnej ochrany

- Doporučenie ICRP č. 60 tvorí základ mnohých medzinárodných a národných noriem a predpisov radiačnej ochrany.
- Na Slovensku je to Vyhláška MZ SR č. 12/2001 nahradená neskôr **Nariadením vlády 345/2006** o základných bezpečnostných požiadavkách na ochranu zdravia pracovníkov a obyvateľov pred ionizujúcim žiarením.
- Radiačná ochrana je súčasťou verejného zdravotníctva, ktoré reguluje **Zákon NR SR 355/2007 o ochrane, podpore a rozvoji verejného zdravia.**
- V Medzinárodnom meritku sa pre oblasť jadrovej energie odporúča norma **IAEA Safety Standarts No. 115** z roku 1996.
- Zákon 355/2007 Z.z. do slovenskej legislatívy preberá PRÁVNE AKTY EURÓPSKYCH SPOLOČENSTIEV A EURÓPSKEJ ÚNIE, z ktorých sa radiačnej ochrany pracovníkov týka **Smernica Rady 96/29/Euratom z 13. mája 1996,** ktorá stanovuje základné bezpečnostné normy ochrany zdravia pracovníkov a obyvateľstva pred nebezpečenstvami vznikajúcimi v dôsledku ionizujúceho žiarenia

Doporučenie ICRP 103 z roku 2007

- Boli prijaté v marci 2007 a nahradili predchádzajúce ICRP 60 z roku 1990.
- ICRP 103 aplikuje, rozvíja a konsoliduje nové poznatky a trendy z oblasti biofyziky. Upresňuje hodnoty radiačných a tkanivových váhových faktorov na určovanie ekvivalentnej a efektívnej dávky.
- Zachováva hlavné princípy radiačnej ochrany: odôvodniteľnosť, optimalizácia a limitovanie ožiarenia. Princípy odôvodniteľnosti a optimalizácie sa rozpracovávajú pre všetky plánované i havarijné situácie pri činnostiach vedúcich k ožiareniu.
- Na zabezpečenie princípu limitovania pre všetky relevantné zdroje ožiarenia, sa zavádzajú medzné dávky a referenčné úrovne pre plánované a havarijné situácie (dose and risk constraints, reference levels for emergency and existing exposure situations).
- Limity ožiarenia zostávajú nezmenené.

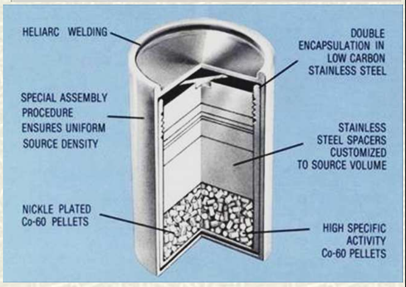
Moderný prístup k radiačnej ochrane

- Pri uplatňovaní princípov radiačnej ochrany sa zásadný dôraz kladie na **optimalizáciu** radiačnej ochrany a v tomto zmysle sa **potláča úloha limitovania dávok**.
- Ak zdôvodnenie činnosti a optimalizácia ochrany boli a sú uskutočňované efektívne, len **vo výnimočných prípadoch by malo dôjsť k aplikácii limitov** individuálnych dávok.

Radiačná udalosť v Mexiku 02.12.2013

Terapeutický žiarič ^{60}Co aktivita 111 TBq (3 kCi)!!! Transport z polikliniky v Tijuane na úložisko RAO v kontajneri. Auto (2,5t VW) s kontajnerom bolo ukradnuté z pumpy a neskôr nájdené opustené, žiarič vybratý z kontajnera a hodený do poľa. Žiarič bol diaľkovým policajným robotom naložený do kontajnera a odvezený (10.12.2013).

PDE 34 Sv/h vo vzdialenosti 1 m.



JAMES CHADWICK

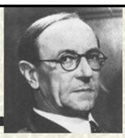
In 1907, while enrolling at the University of Manchester, James Chadwick accidentally found himself in the line for those hoping to major in physics.

Chadwick, who had intended to be a mathematician, was too shy to admit he was mistaken and stayed in line. Thus began the career of one of this century's most distinguished physicists.

In 1913 he received his master's degree and left for Germany to work with Hans Geiger. There, Chadwick was the first to show that beta particles possess a range of energies up to some maximum value.

Trapped in Germany when WW I broke out, Chadwick was imprisoned in a horse stall at a racetrack that served as an internment camp.

JAMES CHADWICK



As soon as the war ended and he gained his freedom, Chadwick returned to England and joined forces **with Ernest Rutherford**. Intrigued by Rutherford's speculation about a **subatomic particle with no charge, Chadwick began a series of experiments to demonstrate the existence of such a particle.**

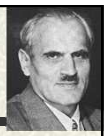
Initially, none of the experiments succeeded. Then, in 1930, Walther Bothe and Herbert Becker described an unusual type of gamma ray produced by **bombarding the metal beryllium with alpha particles**. Chadwick recognized that the properties of this radiation were more consistent with what would be expected from Rutherford's neutral particle.

When Frédéric and Irène Joliot-Curie subsequently claimed that Bothe and Becker's "gamma rays" could eject high energy protons from paraffin, Chadwick knew these were not gamma rays.

The subsequent experiments by which Chadwick proved the existence of the neutron earned him the **1935 Nobel Prize in physics**. Not only did this singular particle provide physicists with a superlative tool for investigating the atom, it was also used to produce a wide variety of new radioisotopes and permitted the initiation of nuclear chain reactions.

Hans Bethe has referred to Chadwick's discovery as the historical beginning of nuclear physics.

ARTHUR HOLLY COMPTON



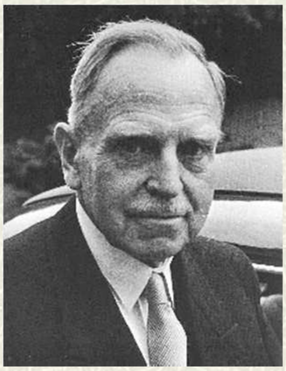
- Enrico Fermi believed that good looks and height were inversely proportional to intelligence, but he was willing to allow an exception in the case of the tall and handsome Arthur Compton. Compton demonstrated the magnitude of his formidable intelligence very early in his career. In 1919, shortly after receiving his doctorate in physics from Princeton, Compton spent a year in Cambridge working under Ernest Rutherford investigating the properties of scattered gamma rays. In the early 1920's, at Washington University in St. Louis, he continued this line of research using X rays instead of gamma rays. He discovered that the scattering of the X rays by graphite lowered their energy. Compton hypothesized that the X rays must be behaving like particles (i.e., photons) that transferred their energy to the electrons of the graphite in a "collision". This would not happen if X rays behaved exclusively as waves. For example, the wavelength (i.e., pitch) of sound does not change as it is reflected off a surface. This provided experimental proof that electromagnetic radiation could exhibit the characteristics of particles as well as waves. In acknowledgement of the importance of this work, Compton was awarded the 1927 Nobel Prize in physics. His research then shifted to investigations of cosmic rays. Measurements at thousands of locations around the world showed that the intensity of cosmic rays was affected by the earth's magnetic field. This provided conclusive evidence that cosmic rays must consist of charged particles. At the outbreak of WW II, Compton's reputation was such that he was asked to direct the Metallurgical Laboratory. The "Met Lab", as it was called, was the organization at the University of Chicago that helped guide the nation's scientific efforts devoted to the development of the atomic bomb

ENRICO FERMI

- Enrico Fermi's first significant accomplishment in nuclear physics was providing a mathematical means for describing the behavior of certain types of subatomic particles, a process concurrently developed by Paul Dirac and which came to be known as Fermi-Dirac statistical mechanics. His next major accomplishment was to successfully explain beta decay by incorporating into the process the production of a new particle which he named the neutrino. Despite the significance of his contributions to theoretical physics, Fermi is best known for his experimental work. When Frédéric and Irène Joliot-Curie first produced artificial radionuclides by bombarding aluminum with alpha particles, Fermi recognized that James Chadwick's recently discovered neutron offered a means to create radionuclides from targets of higher atomic number. In the course of doing so, Fermi noticed that greater activity was induced when the neutron bombardment was performed on a wooden table. He deduced that the neutrons became more effective because they slowed down after being scattered by the wood. He also recognized that neutron bombardment of uranium had the potential to produce a new class of elements, referred to as the transuranics. For his discovery of new radioactive elements and his work with slow neutrons, Fermi was awarded the 1938 Nobel Prize in physics. However, unknown to Fermi and the Nobel Prize Committee, the "new elements" Fermi characterized (with one exception) weren't new at all, they were fission products, i.e., radioisotopes of known elements produced by splitting uranium. Shortly after receiving his Nobel Prize, Fermi left Italy to join the faculty of Columbia University in the United States. Here he supervised a series of experiments that culminated in construction of the CP-1 Pile, the first controlled self-sustaining nuclear chain reaction. This momentous event took place in a squash court under the west stands of Stagg Field at the University of Chicago on December 2, 1942. Fermi thus became the first to control nuclear fission, the very process that in 1934 had led him to the false conclusion that he had discovered the transuranic elements!

OTTO HAHN

- Otto Hahn was the chemist whose discovery of nuclear fission ultimately led to the ending of WW II. The story of Hahn's discovery began in 1938 with a report by Irène Joliot-Curie that bombarding uranium with neutrons had resulted in the production of a radionuclide of thorium, which they later speculated was a transuranium element similar to lanthanum. The astounded Hahn told Irène's husband, Frédéric, that such a thing was nonsense and that he would perform an experiment to prove as much. In the process of duplicating her work, Hahn and co-worker Fritz Strassmann discovered that, among other things, three isotopes of barium had been produced. This was incredible because the mass of barium is about half that of uranium. No known reaction could explain such a huge change. When they published their results (Jan. 6, 1939) Hahn and Strassmann noted that such a thing was "in opposition to all the phenomena observed up to the present in nuclear physics." Hahn, conscious of the fact that as a chemist he was treading in the domain of physics, did not offer an explanation. Instead, he left it up to Lise Meitner, his longtime collaborator, to whom he had sent a letter (December 19, 1938) describing his findings and asking "Perhaps you can suggest some fantastic explanation," which she explained as nuclear fission. Nevertheless, despite the contributions of Strassmann and Meitner, it was Hahn who was awarded the 1944 Nobel Prize in chemistry for the discovery. Unfortunately, Hahn was not at the awards ceremony to receive his prize. At the time he learned of the award, he was being held by the British who were seeking information from him about the failed German effort to develop an atomic bomb. As the Chairman of the Nobel Committee for Chemistry reported "Professor Hahn . . . has informed us that he is regrettably unable to attend this ceremony."



JEAN FRÉDÉRIC JOLIOT & IRÈNE CURIE

- In 1925, Frédéric Joliot accepted the position of special assistant to Marie Curie. The next year, he married Marie's daughter, Irène, forming one of the most remarkable scientific partnerships of all time: Frédéric served the role of chemist, Irène that of physicist. Unfortunately, the early stage of their careers was defined by failure rather than success. Not only did they fail to discover the neutron, misidentifying it as a gamma ray, they also just missed discovering the positron. Later on, however, it was their observations of these very particles that led to their discovery of artificial radioactivity, which is considered to be their greatest triumph. Irène and Frédéric had noted that the bombardment of aluminum with alpha particles resulted in the emission of neutrons and positrons. As expected, the neutrons were emitted only as long as the aluminum was being bombarded by alpha particles. What astonished Frédéric and Irène was the continued emission of positrons long after the alpha source had been removed from the target. Immediately, Frédéric and Irène performed careful analyses which showed that the alpha bombardment had produced a positron-emitting radionuclide of phosphorous from the aluminum. Not only had they produced the first artificial radionuclide, they were the first to experimentally confirm transmutation, the conversion of one element into another element! Up to this point, the only radioactive materials available for medical and scientific research were those that occurred naturally. Now a method was available for creating a wide new variety of radioisotopes. The impact was immense, and for this discovery the Joliot-Curies won the 1935 Nobel Prize for chemistry. Later, during WW II, they helped hamper German efforts to develop an atomic bomb by ensuring that the entire stock of heavy water from the Norsk Hydro Plant was secured and shipped to Britain before France and Norway came under German control. After the war, they made major contributions to the construction of France's first nuclear reactor.

LISE MEITNER

- Lise Meitner, forever linked in people's minds with the monumental discovery of nuclear fission, made many significant contributions to science throughout a long and productive career. Upon receiving a doctorate in physics in 1906, Meitner went to the University of Berlin where she began her collaborations with Otto Hahn. The first significant result of this collaboration was an important technique for purifying radioactive material that took advantage of the recoil energy of atoms produced in alpha decay. Later, at the Kaiser Wilhelm Institute in Austria, she was the first to explain how conversion electrons were produced when gamma ray energy was used to eject orbital electrons. She also provided the first description of the origin of auger electrons, i.e., outer-shell orbital electrons ejected from the atom when they absorbed the energy released by other electrons falling to lower energies. When Nazi Germany annexed Austria in 1938, Meitner, a Jew, fled to Sweden. In her absence, Hahn and Fritz Strassmann continued experiments they had begun earlier with Meitner and demonstrated that barium was produced when a uranium nucleus was struck by neutrons. This was absolutely startling because barium is so much smaller than uranium! Hahn wrote to Meitner, "it [uranium] can't really break up into barium . . . try to think of some other possible explanation." While visiting her nephew Otto Frisch for the Christmas holidays in Denmark, she and Frisch proved that a splitting of the uranium atom was energetically feasible. They employed Niels Bohr's model of the nucleus to envision the neutron inducing oscillations in the uranium nucleus. Occasionally the oscillating nucleus would stretch out into the shape of a dumbbell. Sometimes, the repulsive forces between the protons in the two bulbous ends would cause the narrow waist joining them to pinch off and leave two nuclei where before there had been one. Meitner and Frisch described the process in a landmark letter to the journal *Nature* with a term borrowed from biology: fission.

ERNEST RUTHERFORD

- Ernest Rutherford is considered the father of nuclear physics. Indeed, it could be said that Rutherford invented the very language to describe the theoretical concepts of the atom and the phenomenon of radioactivity. Particles named and characterized by him include the alpha particle, beta particle and proton. Even the neutron, discovered by James Chadwick, owes its name to Rutherford. The exponential equation used to calculate the decay of radioactive substances was first employed for that purpose by Rutherford and he was the first to elucidate the related concepts of the half-life and decay constant. With Frederick Soddy at McGill University, Rutherford showed that elements such as uranium and thorium became different elements (i.e. transmuted) through the process of radioactive decay. At the time, such an incredible idea was not to be mentioned in polite company: it belonged to the realm of alchemy, not science. For this work, Rutherford won the 1908 Nobel Prize in chemistry. In 1909, now at the University of Manchester, Rutherford was bombarding a thin gold foil with alpha particles when he noticed that although almost all of them went through the gold, one in eight thousand would "bounce" (i.e. scatter) back. The amazed Rutherford commented that it was "as if you fired a 15-inch naval shell at a piece of tissue paper and the shell came right back and hit you." From this simple observation, Rutherford concluded that the atom's mass must be concentrated in a small positively-charged nucleus while the electrons inhabit the farthest reaches of the atom. Although this planetary model of the atom has been greatly refined over the years, it remains as valid today as when it was originally formulated by Rutherford. In 1919, Rutherford returned to Cambridge to become director of the Cavendish Laboratory where he had previously done his graduate work under J.J. Thomson. It was here that he made his final major achievement, the artificial alteration of nuclear and atomic structure. By bombarding nitrogen with alpha particles, Rutherford demonstrated the production of a different element, oxygen. "Playing with marbles" is what he called it; the newspapers reported that Rutherford had "split the atom." After his death in 1937, Rutherford's remains were buried in Westminster Abbey near those of Sir Isaac Newton.

WILLIAM DAVID COOLIDGE

- In 1913, William David Coolidge revolutionized the field of radiology by inventing what is now referred to as the Coolidge X-ray tube. No new scientific principles or discoveries were involved, and to Coolidge's employer, the General Electric Company, the invention simply represented a new product. Nevertheless, this new product became a watershed in the field of medicine. The story of its development began in 1905 when Coolidge joined the General Electric Research Laboratory and was given the task of replacing the fragile carbon filaments in electric light bulbs with tungsten filaments. The available tungsten was difficult to work metallurgically, but Coolidge succeeded and his improved light bulb was brought to market in 1911. General Electric also manufactured X-ray tubes and Coolidge recognized that his tungsten filament together with additional modifications could significantly improve the performance of the tube. Coolidge's improved X-ray tube employed a heated tungsten filament as its source of electrons (i.e., the cathode). Since residual gas molecules in the tube were no longer necessary as the electron source, the Coolidge (or hot cathode) tube could be completely evacuated which permitted higher operating voltages. These higher voltages produced higher energy X rays which were more effective in the treatment of deep-seated tumors. In addition, the intensity of the X rays didn't show the tremendous fluctuations characteristic of earlier tubes and the operator had much greater control over the quality (i.e., energy) of the X rays. Coolidge later became Director of the laboratory and eventually Vice-President and Director of Research for General Electric. At the beginning of WW II, he was appointed to a small committee established to evaluate the military importance of research on uranium. This committee's report led to the establishment of the Manhattan District for nuclear weapons development. In 1975, with 83 patents to his credit, William David Coolidge was elected to the National Inventor's Hall of Fame, the only person to receive this honor in his lifetime.

LAURISON S. TAYLOR

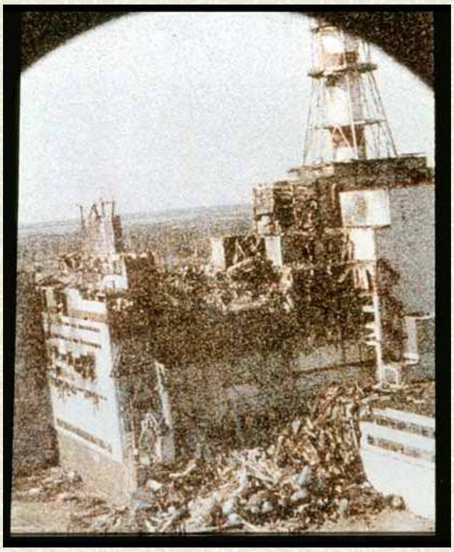
- By the time Lauriston Taylor was 26 years of age, he was Chief of the X-ray group at the National Bureau of Standards and had served as one of three representatives of the United States at the Second International Congress of Radiology in 1928. At the Congress, Taylor and G. Kaye of Great Britain were the driving forces behind the creation of the International Commission on Radiological Protection (ICRP), the world's most influential organization in the field of radiation protection. From 1937 to 1950, Taylor served as Secretary of the ICRP and, from 1934 to 1950, Secretary of almost as influential an organization, the International Commission on Radiation Units and Measurements (ICRU). In 1953 Taylor became Chairman of the ICRU, a position which he held until 1969. A year after the Second Congress of Radiology, Taylor established and became the first president of the National Council on Radiation Protection and Measurements (NCRP), the counterpart in the U.S. to the ICRP and the scientific body from which this nation's regulatory agencies seek guidance regarding radiological protection. At the National Bureau of Standards, Taylor's activities focussed on the measurement of X rays. In fact, he is credited with building the world's first portable radiation survey meter (ca. 1929). He also built the Bureau's first free-air ion chamber, the primary device for measuring the intensity of X rays and the first such chamber to employ guard wires. The use of guard wires was a tremendous improvement because it created a more uniform electric field and greatly reduced the size and weight of these chambers. In the mid 1930's, Taylor constructed the first pressurized ion chamber in the United States which, for a time, was the only operating free-air ion chamber anywhere. When technical contributions such as these are considered together with his many other achievements, it becomes apparent that no one has played a greater role in shaping the profession of radiation protection than Lauriston Taylor.

Three Mile Island

In more recent decades, high profile mishaps have rekindled distrust of radiation.

The 1979 partial meltdown of the Three Mile Island nuclear in the midst of central Pennsylvania's population centers caused near panic.

Chernobyl



Far more devastating was the 1986 explosion of a Ukrainian nuclear reactor at Chernobyl, killing 31. With an estimated 36,000,000 curies of radioactivity released, damaging long-term effects potentially could be far-reaching.