Utilization of e-beam in Cultural Heritage Conservation
The new Collaborating Centre 'RAPID' (from Radiation Processing and Industrial Dosimetry) is an important addition to the IAEA's resources in further serving Member States in feasibility assessment of emerging applications of radiation processing to facilitate adoption and industrial dosimetry intercomparison exercise, vital for effective and efficient application of the technology," said N. Ramamoorthy, Director of the IAEA's Division of Physical and Chemical Sciences.
The core of the Museum's holdings is made up of iconographic stuff such as photographs, documents and correspondence and Maria Sklodowska-Curie's personal effects, such as her glasses, cup, ink bottle, books, coat, purse, letters, notes, etc.
International Year of Chemistry – 2011 *Chemistry – our life, our future*

Resolution of the 63rd Assembly of the United Nations proclaimed the year 2011 as the International Year of Chemistry. Coordinators of the event are UNESCO and the International Union of Pure and Applied Chemistry (IUPAC). Patroness of this event is Marie Curie, née Skłodowska. Among women scientists, she was the first winner of the Nobel Prize, and, among all the scientists, also the only one who received this award twice in different scientific fields (1903 in physics with P. Curie and H. Becquerel, in 1911 in the field of chemistry alone).

The year 2011 marks the one-hundredth anniversary of the Nobel Prize in Chemistry awarded to *Marie Sklodowska Curie*, recognizing her discovery of the elements radium and polonium.
The honorary patron the years of Maria Skłodowska Curie is President Bronisław Komorowski
Unveiling of a bust made the Director IAEA.

Poland and France have been donated to the IAEA a sculpture, dated 1930, by Polish artist Ludwika Nitschowa, representing Marie Curie-Sklodowska, the...
Sculpture in the main building IAEA
Currently the main building is undergoing renovation. The sculpture is located temporarily on the ground floor.
SUR L'ETUDE DES COURBES DE PROBABILITÉ RELATIVES À L'ACTION DES RAYONS X SUR LES BACILLES

Cette Note est un complément théorique à l'exposé des recherches de F. Holweck et de A. Lacassagne sur l'action bactéricide des rayons X (voir ci-dessus). J'admet avec F. Holweck que, pour détruire un bacille, il est nécessaire que la zone sensible de celui-ci absorbe un nombre $s$ minimum de quanta d'une fréquence déterminée; $s$ est le seuil de l'effet pour une radiation donnée et un bacille donné. Soient $n$ le volume de la zone sensible, $a$ sa surface exposée aux rayons, $a$ sa profondeur; si la culture reçoit $x$ quanta par unité de surface, le nombre moyen de quanta absorbés par la zone est $x = \mu n a = \mu a n$, où $\mu$ est le coefficient d'absorption ($\mu$ est supposé faible). La probabilité $P_\mu$ pour l'absorption de $n$ quanta et la probabilité $P$ de survie (ou proportion de survivants) sont alors données par les formules bien connues:

$$P_\mu = \frac{\mu n a e^{-\mu a n}}{n!}, \quad P = \sum_{\mu=1}^{\infty} \frac{\mu n a e^{-\mu a n}}{n!}.$$

Quand $s = 1$, on trouve $P = e^{-n}$. En représentant $\log P$ en fonction de $n$, on obtient une droite dont la pente permet de déterminer $s$.

Quand $s > 1$, $P$ n'est pas une fonction exponentielle simple. En représentant $P$ ou $\log P$ en fonction de $n$ pour diverses valeurs de $s$, ou obtient une série de courbes qu'on a utilisées pour déterminer $s$ et $\mu$, en essayant de superposer, par changement d'échelle des abscisses, la courbe expérimentale à l'une des courbes théoriques.

* [Note de Mme M. C. n° 1, Compt. rend., 196, 202 (1929) — ed.]
1 Séance du 26 décembre 1928.
2 La notion de seuil demande une discussion qui ne peut prendre place dans cette Note.
Skłodowska Curie presented the results of experimental and theoretical studies on the effects of X-rays on bacteria.

Today we can say that Maria Skłodowska Curie’s paper was the first work on radiation sterilization.

This also applies to radiation disinfection and sterylization of historical heritage.
I recommend our article on the event in an electronic form in print is published in June.
We also have a laboratory source of gamma radiation.

The Indian source of the dose rate 9 kGy/h.
We finish work on the construction of a new electron accelerator. It will also be used for radiation sterilization of historic objects.
To the radiation preservation of works of art are used mainly gamma rays

however, note that

in the world is about 10 times more EB installations

Approximately 160 gamma irradiators and 1200 electron accelerator based processing units are in operation worldwide
Electron beam radiation was introduced in the 1950s as a means of sterilizing single-use, disposable healthcare products.
operating principle similar to that of CRT TV

in accelerator energy and beam power is many times greater than the cathode ray tube
Accelerators for radiation technologies

Electrostatic  Resonant  Linear
This chart showing the relationship between dose and thickness

useful penetration depth
depends on beam energy and density of the material
\[ d \ [g/cm^2] = 0.37 \times (E \ [MeV] - 0.2) \]
Please note the characteristic shape of the dose depth distribution

boost dose inside objects to 60%

Depth–dose distribution for electrons of various energies and for $^{60}$Co gamma rays
why is there such an increase of absorbed energy
any object

secondary electron energy is deposited in the ionization spurs
number of spurs increases with radiation dose
boost dose inside objects to 60%  

Multi ionization spurs are formed when electrons end gear in the material  

therefore increases the amount of energy!
disadvantage of the EB method is the limited scope of the radiation

*Dose distribution for two-sided irradiation with 10 MeV electrons – max 10 cm (water)*
Manufacturers of linear electron accelerators

- Varian, USA
- Titan Beta, USA
- RPC Technologies, USA
- American Science & Engineering, Inc., USA
- Mitsubishi Heavy Industries, Japonia
- Technical Systems Ltd, Wlk. Brytania
- Thomson CSF, Francja
- Inst. Aparatury Elektrofizycznej, Rosja
- RIA TORIJ, Rosja
- Res. Inst. of Automation for Machine-Building, China
- Zakład Bad. Aparatury Jądrowej, Świerk, Polska
10 MeV ELECTRON ACCELERATOR  Vertical
10 MeV ELECTRON ACCELERATOR Levels

Energy 10 MeV
EB power 3-5 kW

Dose 10-50 kGy
production up to 50 000 m³/y
Akcelerator 5 MeV, 150 kW
Radia Industry, Japonia
Setup for irradiation at 90°

HUBER + SUHNER, Szwajcaria
another example of the departure of
X-rays irradiate objects can have any thickness!

So far, however, it is quite expensive technology
NFI: Irradiation chamber with contacts EB and X-ray
Converter electron beam radiation of the *X-ray*

- **Energia elektronów**: 5 MeV
- **Moc wiązki elektronów**: 60 kW
- **Obszar wiązki na targecie**: 7x80 cm
- **Grubość targetu**: 0.8-1 mm
- **Gęstość mocy na targecie**: 100 W/cm²

Instytut Fizyki Jądrowej
Nowosybirsk, Rosja
RHODOTRON

very modern and efficient

please see

TT 1000:
do 700 kW; 7 MeV (100 mA)
do 500 kW; 5 MeV (100 mA)

TT 300:
do 200 kW; 10 MeV (20 mA)
do to 135 kW; 5 MeV (27 mA)

TT 200:
do 100 kW; 10 MeV (10 mA)
do to 100 kW; 5 MeV (20 mA)

TT 100:
35 kW; 10 MeV (3.5 mA)

IBA, Belgia
Repeated passage of the electron beam through the impact of accelerating field

route in the shape of a flower - the rose
## Accelerators that are used in INCT

<table>
<thead>
<tr>
<th>Typ akceleratora</th>
<th>Energia Moc wiązki</th>
<th>Zastosowanie</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAE 13/9 liniowy</td>
<td>5-13 MeV 9 kW</td>
<td>Prace badawcze Technologie rad.</td>
</tr>
<tr>
<td>AS 2000 elektrostatyczny</td>
<td>0,1-2 MeV 0,2 kW</td>
<td>Prace badawcze</td>
</tr>
<tr>
<td>IŁU 6 rezonansowy</td>
<td>0,5 - 2 MeV 20 kW</td>
<td>Prace badawcze Technologie rad.</td>
</tr>
<tr>
<td>Elektronika 10/10 liniowy</td>
<td>10 MeV 15 kW</td>
<td>Technologie rad.</td>
</tr>
<tr>
<td>LAE 10 liniowy</td>
<td>10 MeV</td>
<td>Badania podstawowe</td>
</tr>
</tbody>
</table>
## Radiation Sterilization

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accelerator</strong></td>
<td>Elektronika 10/10</td>
</tr>
<tr>
<td>Energy</td>
<td>10 MeV</td>
</tr>
<tr>
<td>EB power</td>
<td>15 kW</td>
</tr>
<tr>
<td>Sweep width</td>
<td>65 cm</td>
</tr>
<tr>
<td>pobór energii el.</td>
<td>120 kVA</td>
</tr>
<tr>
<td><strong>Building</strong></td>
<td></td>
</tr>
<tr>
<td>Technical Area</td>
<td>814 m²</td>
</tr>
<tr>
<td>Total area</td>
<td>9230 m²</td>
</tr>
<tr>
<td>powierzchnia mag.</td>
<td>2x288 m²</td>
</tr>
<tr>
<td><strong>PARAMETRY PROCESU</strong></td>
<td></td>
</tr>
<tr>
<td>Conveyor speed</td>
<td>0.3 - 7 m/min.</td>
</tr>
<tr>
<td>wydajność</td>
<td>10 000 kg kGy/h</td>
</tr>
<tr>
<td>wymiary pojemnika</td>
<td>56x45x(10-30) cm ; 0.05 m³</td>
</tr>
</tbody>
</table>
Pilot Plant for Radiation Sterilization
Method of placement and labeling of the product
For the sterilization of *Cultural Heritage*, high-energy electron beams are typically required to achieve penetration of the product and packaging. When evaluating e-beam irradiation for the purpose of sterilization, product density, size, orientation, and packaging must be considered. In general, e-beam irradiation performs best when used on low-density, uniformly packaged products.
Advantages of EB in comparison with gamma ray

1. smaller effect of oxidation and postradiation degradation
2. large speed the process, a large dose rate (irradiation time of a few seconds)
3. methods is better perceived by the public
   • there is no threat of a terrorist attack, it is slightly larger electrical equipment
   • you can simply turn off and go home
In the case of EB - the high dose (irradiation time of a few seconds)
significantly lower the efficiency of postradiation oxidation - degradation

Oxygen continuously diffuses into the interior of the material during irradiation

Oxygen does not manage to diffuse into the material
I will say about this in the next lecture.

Marie and Pierre's honeymoon held on bikes in the vicinity of the presidential palace.
More about Polish experiences in the field of radiation preservation of valuable objects for the culture I have a chance to say in subsequent speeches.
Thank You for Your Attention!
As an example to compare the two methods I have chosen the process of radiation preservation of paper

Research on radiation preservation of paper
The goal of this work was to establish connections between gamma radiation doses and a change of some physical and chemical paper properties (radiation paper disinfection approach). In all read works referring to radiation paper disinfection cobalt isotope $^{60}$Co is used.

The comparison was made between this radiation and rapid electrons radiation (accelerators generated) that so far has not been used for preservation.

Exploration made so far included paper resistance changes as cooper-number and pH-water extract have been investigated. In addition, whiteness changes of paper have been registered. The rapid electrons radiation has proved to be more profitable.
It is of interest to determine which radiation is more effective.

The microbiological studies carried out on two strains of fungi (Aspergillus niger and Charetomium globulum, both grown in the Agriculture University, Faculty of Wood Protection) proved that both types of radiation are similar effective.
Only compare the effects of gamma rays and EB on the properties of paper
## Breaking length of Whatman`s paper depending on dose, kind or radiation and direction of test coupon

<table>
<thead>
<tr>
<th>Dose [kGy]</th>
<th>Gamma radiation</th>
<th>Electron beam</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Direction n</td>
<td>Direction r</td>
</tr>
<tr>
<td></td>
<td>σ</td>
<td>s</td>
</tr>
<tr>
<td>0</td>
<td>1.439</td>
<td>0.040</td>
</tr>
<tr>
<td>1</td>
<td>1.431</td>
<td>0.055</td>
</tr>
<tr>
<td>5</td>
<td>1.455</td>
<td>0.063</td>
</tr>
<tr>
<td>10</td>
<td>1.369</td>
<td>0.044</td>
</tr>
<tr>
<td>25</td>
<td>1.395</td>
<td>0.035</td>
</tr>
</tbody>
</table>

**σ** - test resistant temperature = 21°C  
**humidity of air = 55%**

## Breaking length of pulp paper in dependent of dose, kind or radiation and direction of test coupon

<table>
<thead>
<tr>
<th>Dose [kGy]</th>
<th>Gamma radiation</th>
<th>Electron beam</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Direction n</td>
<td>Direction r</td>
</tr>
<tr>
<td></td>
<td>σ</td>
<td>s</td>
</tr>
<tr>
<td>0</td>
<td>2.283</td>
<td>0.192</td>
</tr>
<tr>
<td>1</td>
<td>2.231</td>
<td>0.147</td>
</tr>
<tr>
<td>5</td>
<td>2.250</td>
<td>0.151</td>
</tr>
<tr>
<td>10</td>
<td>2.321</td>
<td>0.117</td>
</tr>
<tr>
<td>25</td>
<td>2.162</td>
<td>0.094</td>
</tr>
</tbody>
</table>

**s** - standard deviation

small decrease, slightly less degradation of the EB