

**Advanced ideas and experiments for the new Dubna Neutron Source (DNS-IV).
The related moderators and infrastructure**

FLNP workshop 6-7 September

Protons and neutrons in nuclear medicine

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**FLEROV LABORATORY
OF NUCLEAR REACTIONS**



Modern Nuclear Physics@Nuclear Medicine

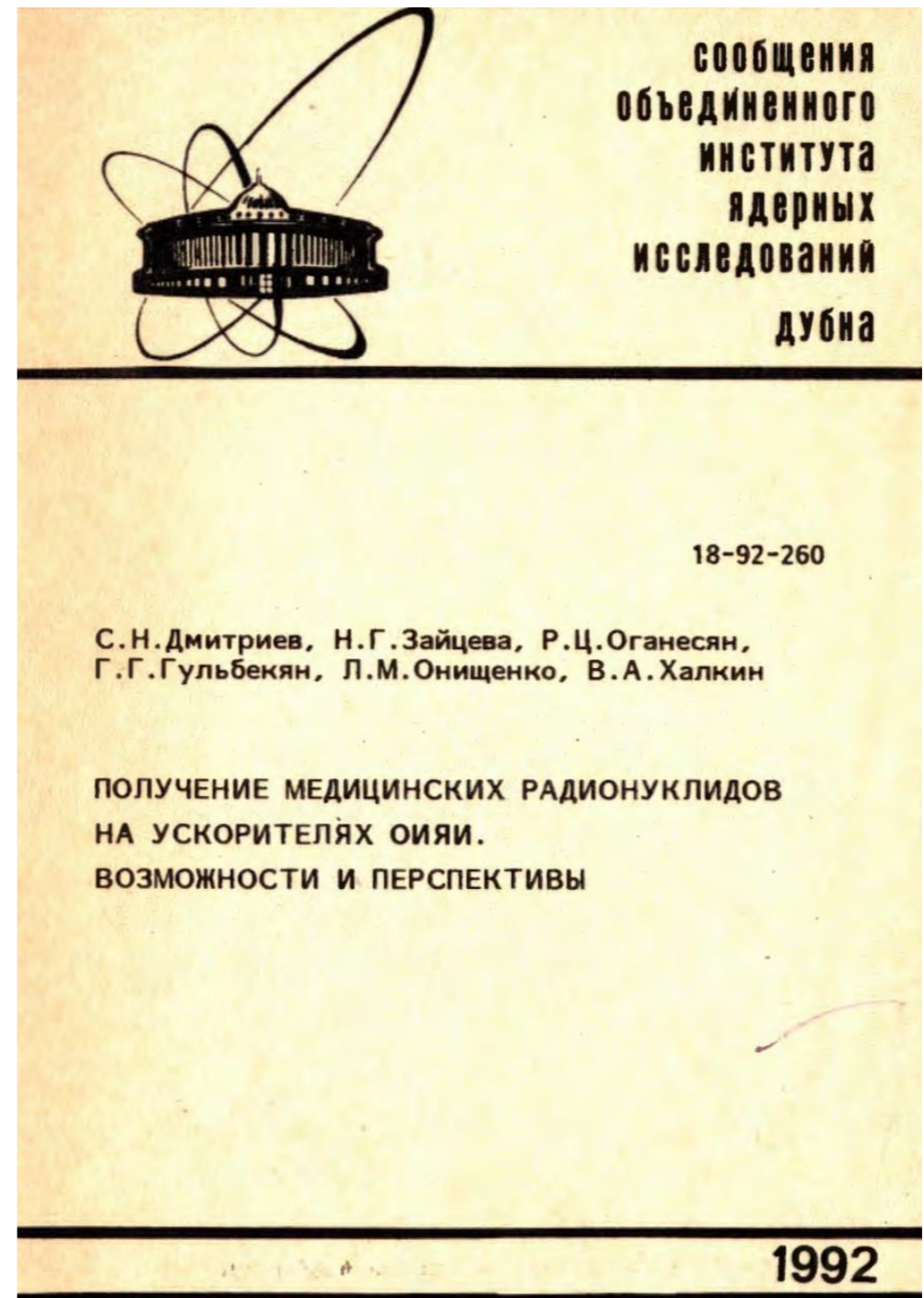
state-of-the-art techniques:

radiation oncology = hadrontherapy
(1967 Phasatron)

**Radionuclides production
(coupled to radiochemical separation)
methods**

medical imaging = nuclear imaging
(detectors, modeling etc.)

**Ускорители ОИЯИ и высокий уровень
исследований, накопленный опыт по
радиохимии - база для получения
широкого спектра радионуклидов для
различных исследований**



ФЕДЕРАЛЬНОЕ МЕДИКО-БИОЛОГИЧЕСКОЕ АГЕНТСТВО:

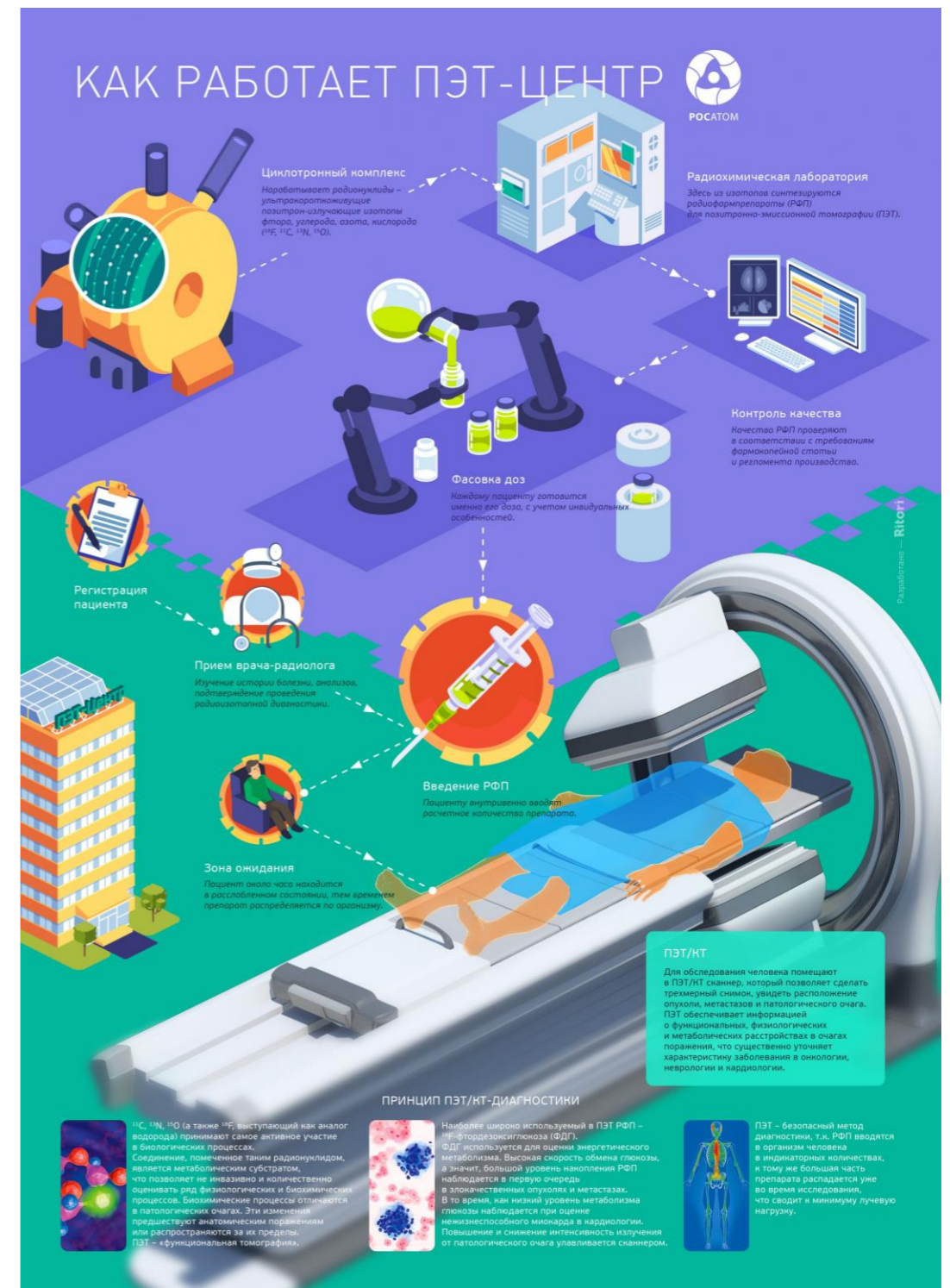
Ядерная медицина – направление современной медицины, использующее радиоактивные вещества и свойства атомного ядра для **диагностики** и **терапии** в различных областях научной и практической медицины



Ежегодно около 50 млн медицинских исследований!

Radionuclide Diagnosis and Therapy

- RN Diagnosis: imaging disease
 - penetrating radiation: β^+ emission (PET - ^{18}F etc.)
 - γ emission (SPECT - $^{99}\text{Mo}/^{99\text{m}}\text{Tc}$, ^{201}Tl etc.)
 - 80%
- RN Therapy
 - particles: α , β^- or Auger e^-
 - ^{153}Sm , ^{90}Y , ^{131}I , ^{226}Ra
- Theranostics
- Radiation therapy



Production methods and facilities

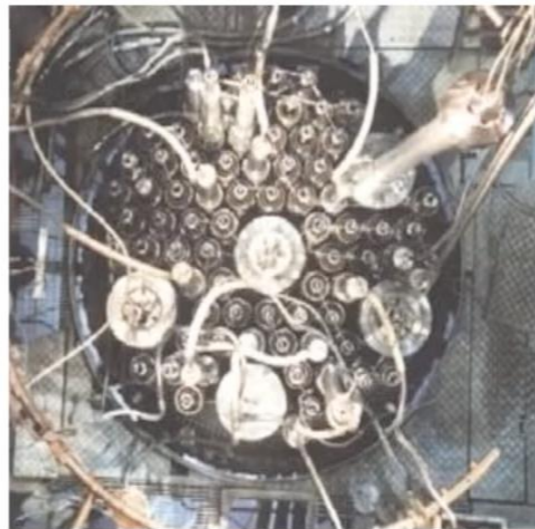
Generator



Protons



Reactor



Photons



Mother/daughter
decay

11 - 18 MeV - PET RN
30 and 70 MeV - SPECT RN
new developments are needed

(p, xn)

(neutron capture)

thermal and fast neutrons
 $10^{12} - 10^{15} \text{ n/cm}^2 \text{ s}$

(γ, xn)

10 - 50 MeV

Production methods and facilities

| CHARACTERISTIC | PRODUCTION METHOD | | | |
|---|---|---|---|--|
| | LINEAR ACCELERATOR/ CYCLOTRON | NUCLEAR REACTOR (FISSION) | NUCLEAR REACTOR (NEUTRON ACTIVATION) | RADIONUCLIDE GENERATOR |
| Bombarding particle | Proton, alpha | Neutron | Neutron | Production by decay of parent |
| Product | Neutron poor | Neutron excess | Neutron excess | Neutron poor or excess |
| Typical decay pathway | Positron emission, electron capture | Beta-minus | Beta-minus | Several modes |
| Typically carrier free | Yes | Yes | No | Yes |
| High specific activity | Yes | Yes | No | Yes |
| Relative cost | High | Low | Low | Low (^{99m}Tc) High (^{82}Rb) |
| Radionuclides for nuclear medicine applications | ^{11}C , ^{13}N , ^{15}O , ^{18}F , ^{57}Co , ^{67}Ga , ^{68}Ge , ^{111}In , ^{123}I , ^{201}Tl | ^{99}Mo , ^{131}I , ^{133}Xe | ^{32}P , ^{51}Cr , ^{89}Sr , ^{125}I , ^{153}Sm | ^{68}Ga , ^{81m}Kr , ^{82}Rb , ^{90}Y , ^{99m}Tc |

| Product isotope | Half-life | Target isotope | Natural abund. % | Inter-mediate isotope | Half-life | $\Phi = 10^{14} \text{ cm}^{-2}\text{s}^{-1}$ | | | $\Phi = 10^{15} \text{ cm}^{-2}\text{s}^{-1}$ | | |
|--|-----------|-------------------|------------------|-----------------------|-----------|---|------------------|--------------|---|------------------|--------------|
| | | | | | | T_{irr} d | T_{d} d | Yield GBq/mg | T_{irr} d | T_{d} d | Yield GBq/mg |
| Production via (2n, γ) reactions | | | | | | | | | | | |
| ^{166}Dy | 3.4 d | ^{164}Dy | 28 | ^{165}Dy | 2.35 h | 10 | 1 | 2 | 5 | 1 | 100 |
| ^{188}W | 69.8 d | ^{186}W | 28 | ^{187}W | 0.99 d | 100 | 10 | 0.002 | 50 | 10 | 0.1 |
| Indirect production via (n, γ) β^- | | | | | | | | | | | |
| ^{47}Sc | 3.3 d | ^{46}Ca | 0.004 | ^{47}Ca | 4.5 d | 10 | 1 | 0.5 | 10 | 1 | 5 |
| ^{125}I | 59.4 d | ^{124}Xe | 0.10 | ^{125}Xe | 17 h | 7 | 7 | 6 | 4 | 7 | 20 |
| ^{131}I | 8.0 d | ^{130}Te | 34 | ^{131}Te | 25 min | 28 | 2 | 0.1 | 28 | 2 | 1 |
| ^{131}Cs | 9.7 d | ^{130}Ba | 0.11 | ^{131}Ba | 12 d | 7 | 7 | 0.7 | 7 | 7 | 7 |
| ^{161}Tb | 6.9 d | ^{160}Gd | 22 | ^{161}Gd | 4 min | 14 | 0.5 | 0.4 | 14 | 0.5 | 4 |
| ^{177}Lu | 6.7 d | ^{176}Yb | 12.8 | ^{177}Yb | 1.9 h | 14 | 1 | 0.6 | 14 | 1 | 4 |
| ^{199}Au | 3.1 d | ^{198}Pt | 7.2 | ^{199}Pt | 31 min | 7 | 0.5 | 0.7 | 7 | 0.5 | 7 |
| ^{227}Ac | 21.7 a | ^{226}Ra | 0 | ^{227}Ra | 42 min | 100 | 30 | 0.02 | 28 | 30 | 0.03 |
| Indirect production via (n,f) | | | | | | | | | | | |
| ^{99}Mo | 2.8 d | ^{235}U | 0.72 | | | 7 | 1 | 5.7 | | | |
| ^{131}I | 8.0 d | ^{235}U | 0.72 | | | 7 | 12 | 0.7 | | | |
| ^{133}Xe | 5.3 d | ^{235}U | 0.72 | | | 7 | 7 | 3 | | | |

***Existing Accelerator Facilities
for Radioisotope Production at High Intensity Proton Beam of
Intermediate Energy***

- **Los Alamos National Laboratory (NM, USA), 100 MeV, 200 μ A**
- **Brookhaven National Laboratory (NY, USA), 200 MeV, 90 μ A**
- **TRIUMF (Vancouver, Canada), 110 MeV, 500 MeV, 70 μ A**
- **iThemba Laboratory (Cape Town, South Africa), 66 MeV, 250 μ A**
- **Institute for Nuclear Research (Troitsk, Russia), 160 MeV, 120 μ A**
- **ARRONAX GIP (Nantes, France), 70 MeV, 2 x 100 μ A**

Proposed Accelerator Facilities for Radioisotope Production at High Intensity Proton Beam of Middle Energy

- **Institute for Nuclear Research of National Academy of Sciences of Ukraine (Kiev)**
H⁺ Cyclotron, 70 MeV, 100 μA (⁸²Sr production from RbCl-target)
- **Positron Corporation (Illinois, USA)**
H⁻ Cyclotron - 70 MeV, 2x375 μA: ⁸²Sr production
- **Petersburg Nuclear Physics Institute**
H⁻ Cyclotron - 80 MeV, 100-200 μA, Isotope separator facility: ⁸²Sr from Y-target
- **Proton Engineering Frontier Project (Gyeongju, South Korea)**
LINAC - 100 MeV, >300 μA
- **Legnaro National Laboratory, INFN (Padova, Italy)**
Cyclotron - 70 MeV, 2x400 μA
- **National Institute for Radioelements, IRE and IBA (Belgium)**
Cyclotron - 350 MeV, 1000 μA (Ta-target to produce neutrons for ⁹⁹Mo)
- **Institute for Nuclear Research (Troitsk, Russia)**
H⁻ Cyclotron – 70 or 120 MeV, ~1000 μA: production of ⁸²Sr, ^{117m}Sn, ²²⁵Ac, ²²³Ra

New Demands

**году несколько миллионов человек в мире не прошли диагностическое обследование
(7 млн. доз)**


**основная тенденция - увеличение использования терапевтических РФП
и разработка новых методов получения РН и РФП**

развитие малых производств и ядерных аптек

**«...technical evolution that has led
to a medical revolution...»**

возвращение исследований в научные лаборатории!


150-лет Периодическому закону Д. И. Менделеева



Периодическая система элементов Д. И. Менделеева
Periodic Table of the Elements

РАЗДВИГАЕМ ГРАНИЦЫ ИЗВЕСТНОГО
EXPANDING THE FRONTIERS OF KNOWLEDGE

ОБЪЕДИНЕННЫЙ ИНСТИТУТ ЯДЕРНЫХ ИССЛЕДОВАНИЙ
JOINT INSTITUTE FOR NUCLEAR RESEARCH



| | | | | | | | | | | | | | | | | | | |
|---------------------------------|-----------------------------------|---------------------------------|---|---------------------------------------|-------------------------------------|------------------------------------|----------------------------------|--------------------------------------|--|---------------------------------------|--|----------------------------------|------------------------------------|--------------------------------------|--|-------------------------------------|------------------------------------|----------------------------|
| 1 | | | | | | | | | | | | | 18 | | | | | |
| 1 H Hydrogen Водород | | | | | | | | | | | | | | | | | 2 He Helium Гелий | |
| 3 Li Lithium Литий | 4 Be Beryllium Бериллий | | | | | | | | | | | | | | | | | 10 Ne Neon Неон |
| 11 Na Sodium Натрий | 12 Mg Magnesium Магний | | | | | | | | | | | | | | | | | 18 Ar Argon Аргон |
| 19 K Potassium Калий | 20 Ca Calcium Кальций | 21 Sc Scandium Скандий | 22 Ti Titanium Титан | 23 V Vanadium Ванадий | 24 Cr Chromium Хром | 25 Mn Manganese Марганец | 26 Fe Iron Железо | 27 Co Cobalt Кобальт | 28 Ni Nickel Никель | 29 Cu Copper Медь | 30 Zn Zinc Цинк | 31 Ga Gallium Галлий | 32 Ge Germanium Германий | 33 As Arsenic Мышьяк | 34 Se Selenium Селен | 35 Br Bromine Бром | 36 Kr Krypton Криптон | |
| 37 Rb Rubidium Рубидий | 38 Sr Strontium Стронций | 39 Y Yttrium Иттрий | 40 Zr Zirconium Цирконий | 41 Nb Niobium Ниобий | 42 Mo Molybdenum Молибден | 43 Tc Technetium Технеций | 44 Ru Ruthenium Рутений | 45 Rh Rhodium Родий | 46 Pd Palladium Палладий | 47 Ag Silver Серебро | 48 Cd Cadmium Кадмий | 49 In Indium Индий | 50 Sn Tin Олово | 51 Sb Antimony Сурьма | 52 Te Tellurium Теллур | 53 I Iodine Йод | 54 Xe Xenon Ксенон | |
| 55 Cs Caesium Цезий | 56 Ba Barium Барий | 57 La Lanthanum Лантан | 58 Ce Cerium Церий | 59 Pr Praseodymium Прозердий | 60 Nd Neodymium Неодим | 61 Pm Promethium Прометий | 62 Sm Samarium Самарий | 63 Eu Europium Европий | 64 Gd Gadolinium Гадолиний | 65 Tb Terbium Тербий | 66 Dy Dysprosium Диспрозий | 67 Ho Holmium Гольмий | 68 Er Erbium Эрбий | 69 Tm Thulium Тулий | 70 Yb Ytterbium Иттербий | 71 Lu Lutetium Лютеций | | |
| 87 Fr Francium Франций | 88 Ra Radium Радий | 89 Ac Actinium Актиний | 104 Rf Rutherfordium Резерфордий | 105 Db Dubnium Дубний | 106 Sg Seaborgium Сиборгий | 107 Bh Bohrium Борий | 108 Hs Hassium Хассий | 109 Mt Meitnerium Мейтнерий | 110 Ds Darmstadtium Дармштадтий | 111 Rg Roentgenium Рентгений | 112 Cn Copernicium Коперниций | 113 Nh Nihonium Ниголий | 114 Fl Flerovium Флеровий | 115 Mc Moscovium Московский | 116 Lv Livermorium Ливерморий | 117 Ts Tennessine Теннесси | 118 Og Oganesson Оганесон | |

Лантаноиды / Lanthanides

| | | | | | | | | | | | | | |
|-----------------------------|---------------------------------------|---------------------------------|------------------------------------|---------------------------------|---------------------------------|-------------------------------------|-------------------------------|-------------------------------------|--------------------------------|-----------------------------|------------------------------|-----------------------------------|---------------------------------|
| 58 Ce Cerium Церий | 59 Pr Praseodymium Прозердий | 60 Nd Neodymium Неодим | 61 Pm Promethium Прометий | 62 Sm Samarium Самарий | 63 Eu Europium Европий | 64 Gd Gadolinium Гадолиний | 65 Tb Terbium Тербий | 66 Dy Dysprosium Диспрозий | 67 Ho Holmium Гольмий | 68 Er Erbium Эрбий | 69 Tm Thulium Тулий | 70 Yb Ytterbium Иттербий | 71 Lu Lutetium Лютеций |
|-----------------------------|---------------------------------------|---------------------------------|------------------------------------|---------------------------------|---------------------------------|-------------------------------------|-------------------------------|-------------------------------------|--------------------------------|-----------------------------|------------------------------|-----------------------------------|---------------------------------|

Актиноиды / Actinides

| | | | | | | | | | | | | | |
|------------------------------|---|----------------------------|-----------------------------------|-----------------------------------|-----------------------------------|-----------------------------|----------------------------------|---------------------------------------|---------------------------------------|--------------------------------|---------------------------------------|----------------------------------|--------------------------------------|
| 90 Th Thorium Торий | 91 Pa Protactinium Протактиний | 92 U Uranium Уран | 93 Np Neptunium Нептуний | 94 Pu Plutonium Плутоний | 95 Am Americium Америций | 96 Cm Curium Кюрий | 97 Bk Berkelium Берклий | 98 Cf Californium Калифорний | 99 Es Einsteinium Эйнштейний | 100 Fm Fermium Фермий | 101 Md Mendelevium Менделеев | 102 No Nobelium Нобелий | 103 Lr Lawrencium Лоуренсий |
|------------------------------|---|----------------------------|-----------------------------------|-----------------------------------|-----------------------------------|-----------------------------|----------------------------------|---------------------------------------|---------------------------------------|--------------------------------|---------------------------------------|----------------------------------|--------------------------------------|

Атомный номер Atomic number

Символ Symbol

Атомная масса Atomic mass

Название Name

Год открытия Year of discovery


Электронная конфигурация Electronic configuration

■ s-элементы ■ d-элементы
■ p-элементы ■ f-элементы

НАУКА СБЛИЖАЕТ НАРОДЫ | SCIENCE BRINGING NATIONS TOGETHER

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ООН: 2019 год - Международный год Периодической таблицы химических элементов



N. Aksenov, FLNR@DNS workshop, 7 september 2018

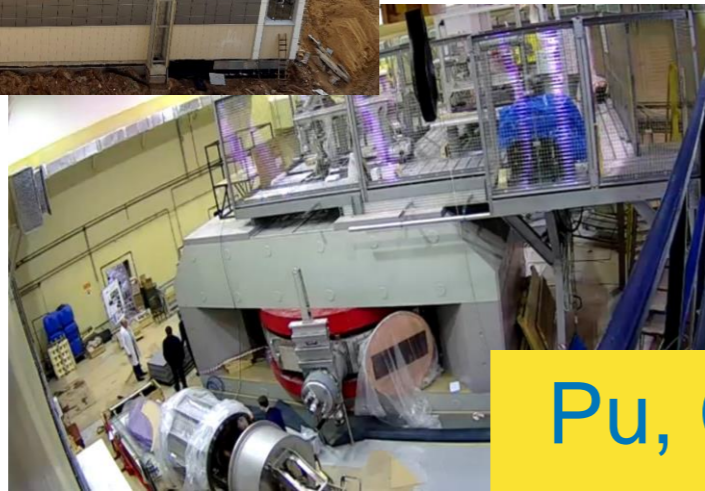
12



NEW FACILITY FOR SUPER HEAVY ELEMENT RESEARCH: SHE-FACTORY

- ★ New experimental facilities
- Discovery of new SHE
- High statistics experiments
- Study of elements with $Z = 112 - 118$
- ...

DC-280



Pu, Cm, Cf, Bk, Es isotopes production is highly needed!!!

EPJ Web of Conferences **131**, 08001 (2016)

Nobel Symposium NS160 – Chemistry and Physics of Heavy and Superheavy Elements

Status and perspectives of the Dubna superheavy element factory

Sergey Dmitriev^a, Mikhail Itkis, and Yuri Oganessian

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**THANK YOU
FOR YOUR
ATTENTION !**