Concept of new ADS scheme based on nuclear relativistic technology (NRT) - first results and perspectives

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Baldin seminar, October 5, 2010,
Dubna

Four IAEA basic requirements for future atomic power engineering:

1. Unlimited reserves of raw material for the production of nuclear fuel.
2. Invariability of the radiation background of the Earth.
3. Guarantee of a non profiliration regime.
4. Natural safety of nuclear power plants.

To be or not to be for future world scale atomic energy production is a **satisfaction of the first IAEA requirement.**

Indeed if there are no enough reserves of raw material for the production of nuclear fuel so there are no subject for discussion

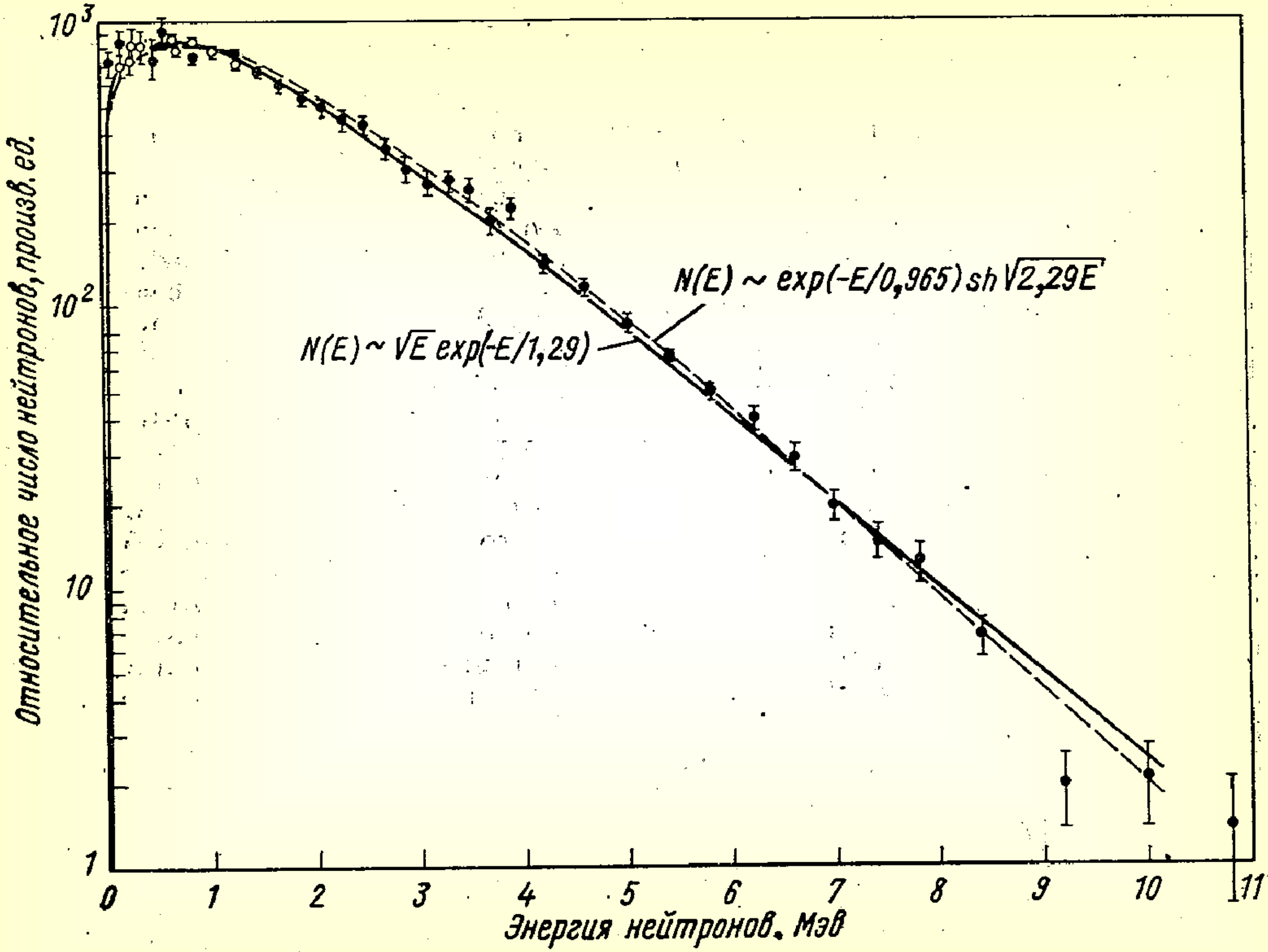

Рис. 8.1. Спектр нейтронов при делении ^{235}U тепловыми нейтронами: О — камера Вильсона; ● — метод времени пролета и фотоэмульсии

Baldin seminar, October 5, 2010,
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Introduction

- We hope that many problems of future world scale of nuclear power engineering could be solved with aid of new ADS scheme based on the proposed relativistic nuclear technology (RNT).

- RNT based on generation and use possibly hardest neutron spectrum inside of subcritical core of ADS system.

- It is waited that such neutron spectrum could ensure an utilization of spent nuclear fuel (SNF) including transmutation of long-lived components radioactive wastes (RAW) as well as simultaneous nuclear energy production

Main features of RNT scheme

1. Large volume (“quasi-infinite”) of subcritical core from natural (depleted) uranium or thorium.

Such cores are deeply subcritical. Indeed the coefficient of fission neutron multiplication within infinite medium of natural uranium consists of ~ 0,36.
It is important that only in deeply subcritical system we can obtain the neutron spectrum much more hard than fission one.

As experiments show large volume of subcritical core allows to involve in neutron production secondary and subcequent intra-nuclear cascades.

By definition in any ADS scheme 4-th IAEA requirement is fulfilled

Main features of RNT scheme

2. **More high (up to 10 GeV) incident energy in comparison with traditional ADS value (~ 1 GeV)**

This allows to diminish the beam flux for the same beam power and essentially increases a share of beam energy contributing to generation of high energy part of neutron spectrum inside of an active core.

In particular due to increasing incident energy an additional mechanism of hardening of neutron spectrum is switching on- namely generation of different mesons.

Advantages of RNT scheme:

1. Extremely hard neutron spectrum allows effectively "burn" a basic material of subcritical core (^{238}U or ^{232}Th) without use of additional "classical" fissile materials ($^{233\text{-}235}$U and ^{239}Pu).

Due to very large (or practically infinite) reserves of depleted and natural uranium and natural thorium the first and third IAEA requirements could be fulfilled.

2. Increase of incident beam energy with simultaneous decrease of its flux makes much more simple the problems of entrance beam window and cooling of subcritical target.

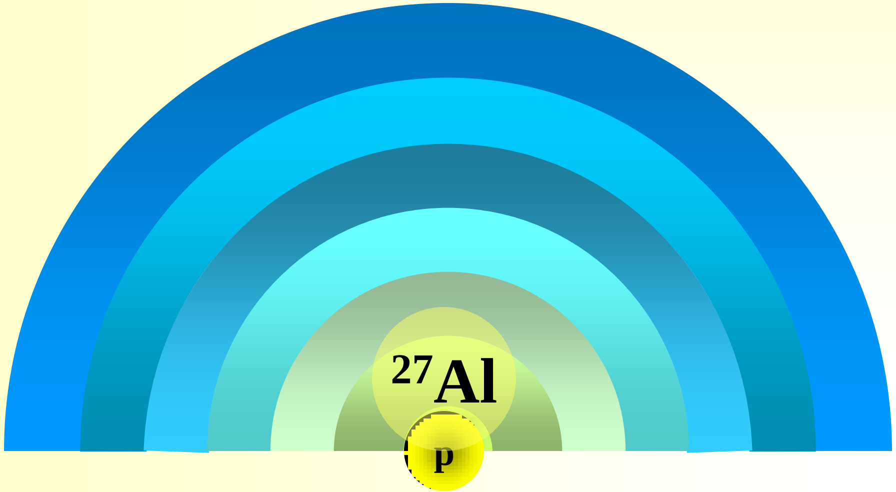
3. There are some plausible grounds to adopt that RNT could provide new promising possibilities for direct (without complicated radio-chemical procedures) utilization of spent fuel elements from nuclear power plants and profitable production of nuclear energy.

Advantages of RNT scheme:

These possibilities define by the properties of the intra-nuclear cascade.

Indeed, in quasi-infinite active core the generation of neutron spectra during intra-nuclear cascade is rather similar for heavy as well as for much more light target nuclei.

In the interaction of a relativistic proton with a light nucleus is generated fewer neutrons, but with much more hard spectrum. - - - - - - - ->



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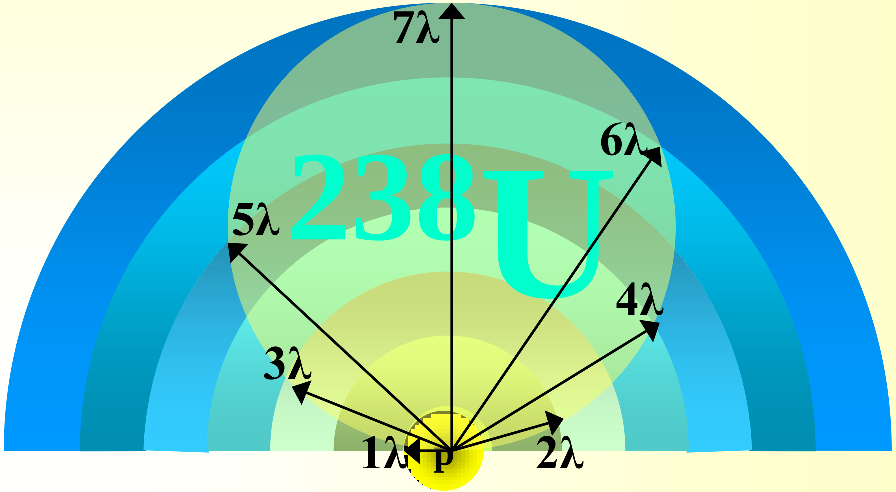

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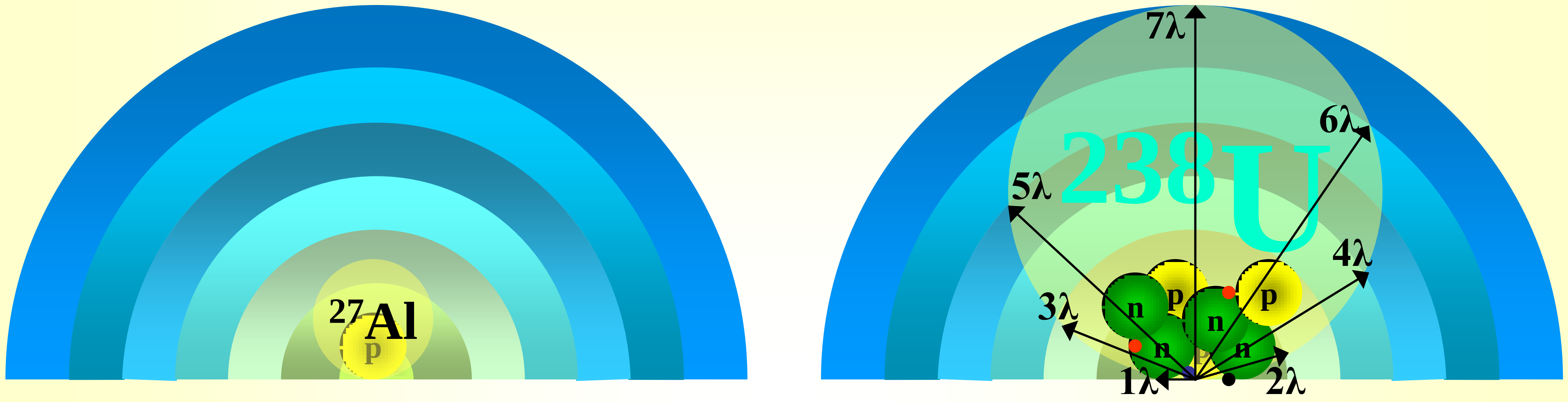

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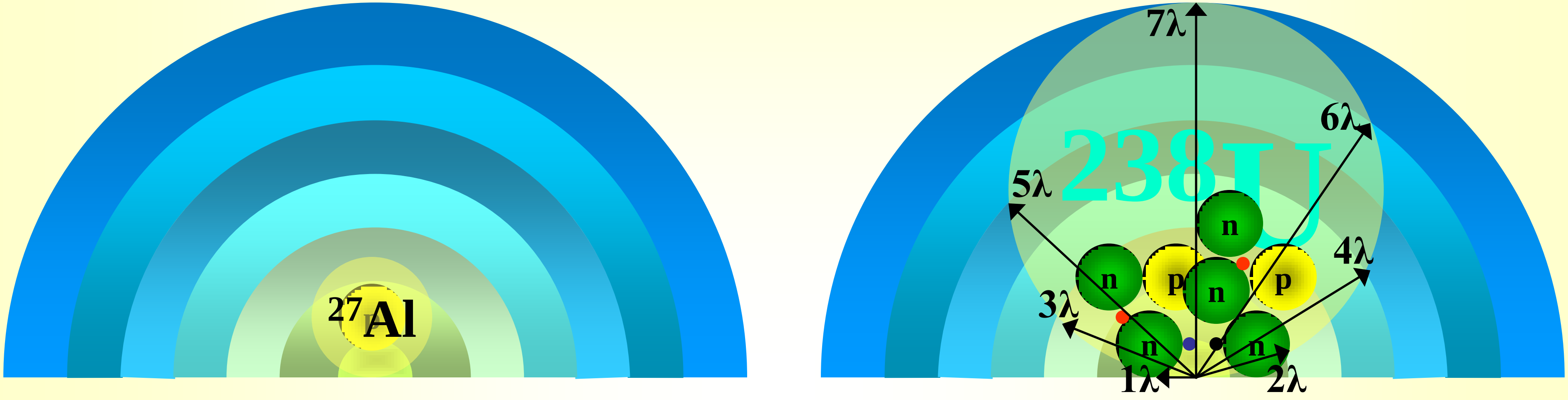

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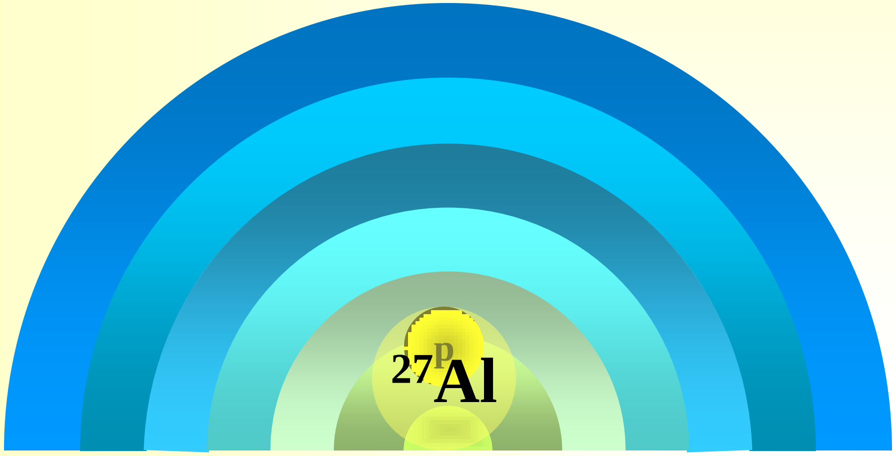
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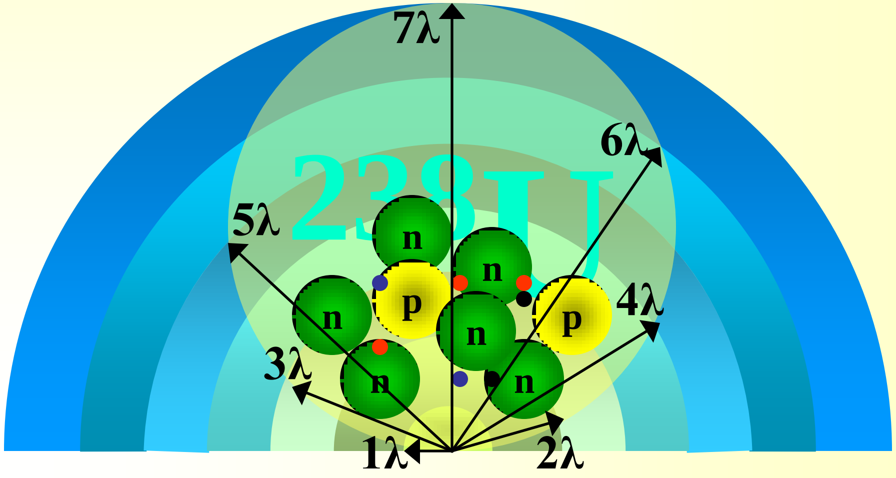
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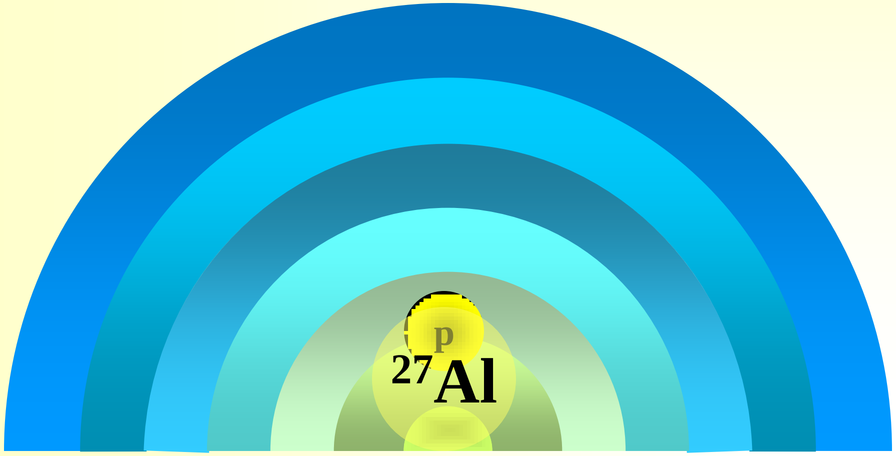
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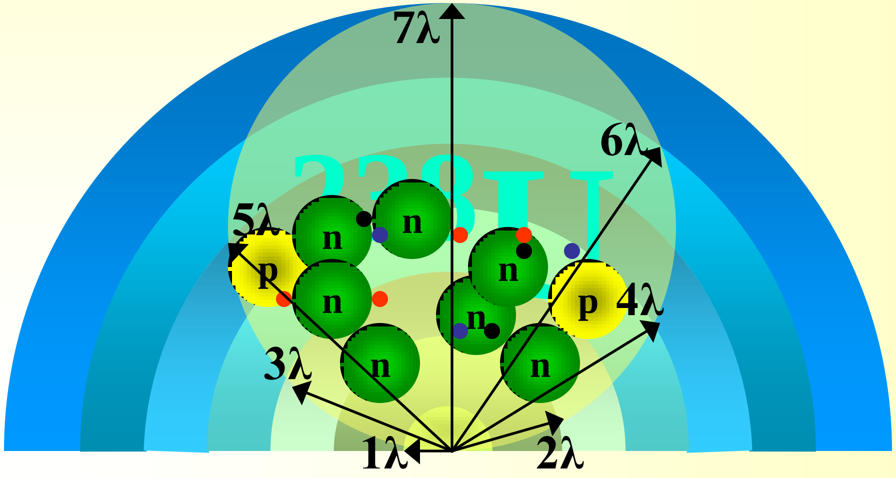
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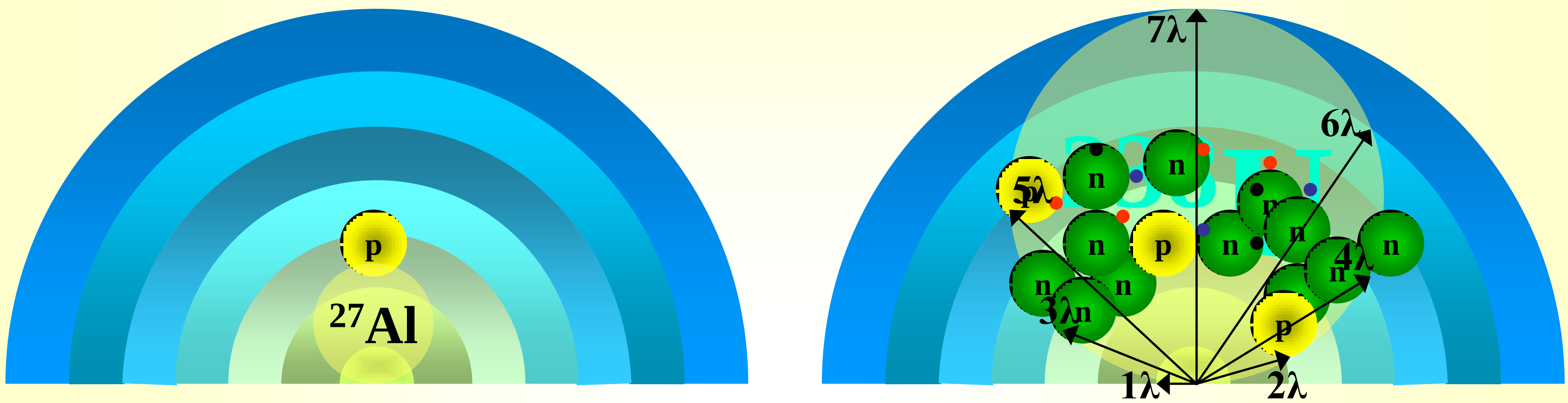
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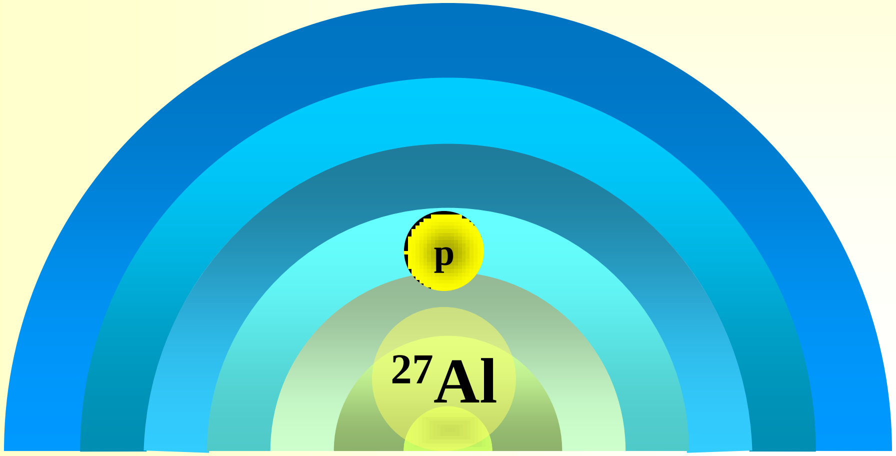
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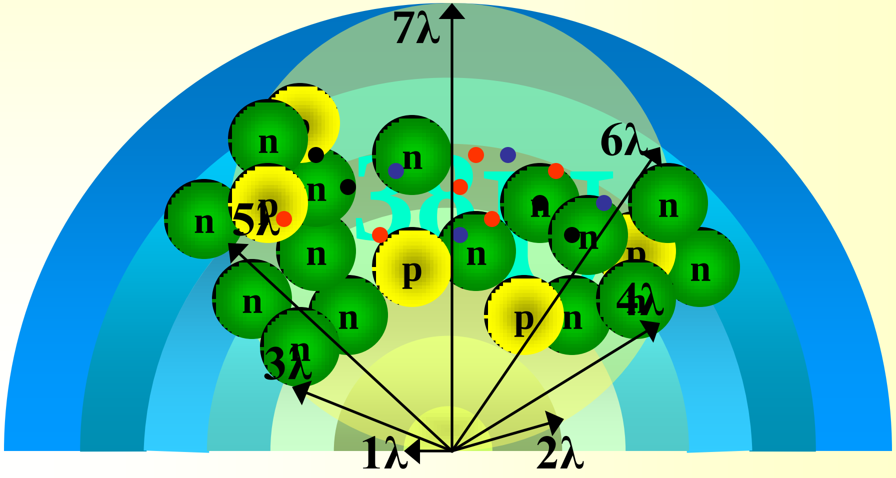
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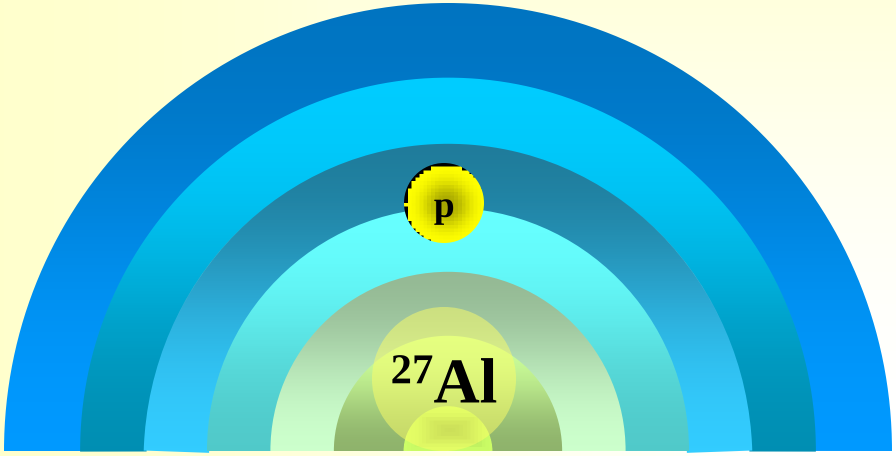
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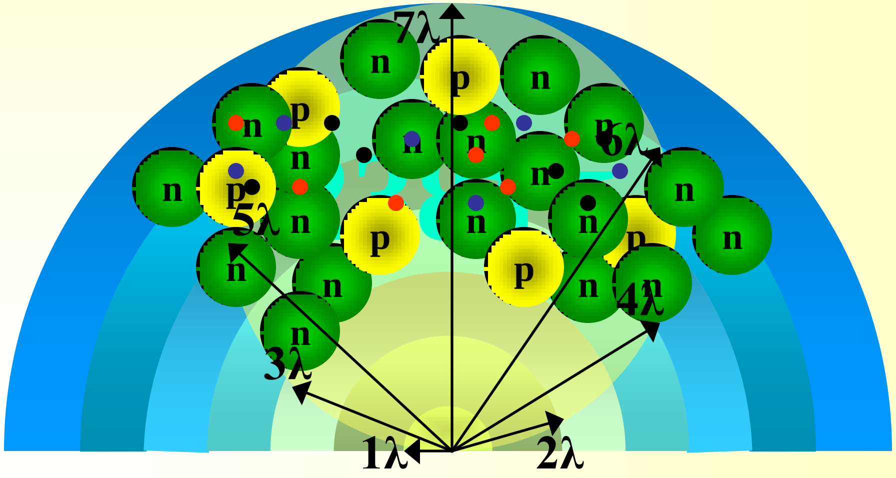
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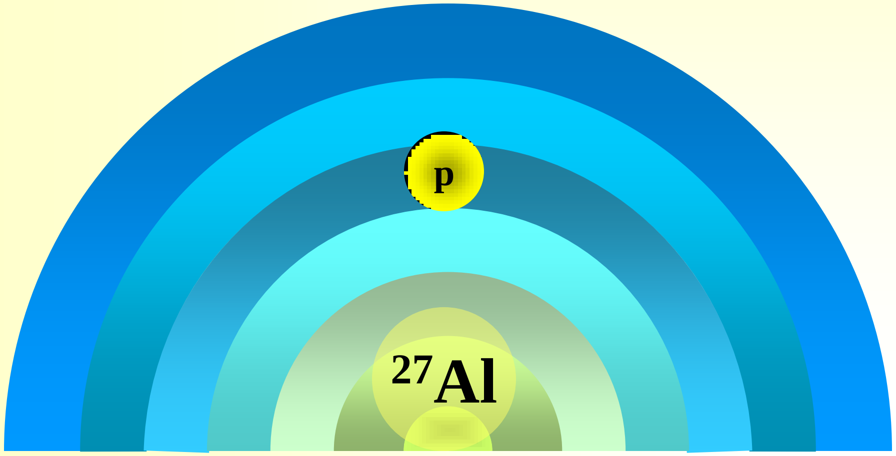
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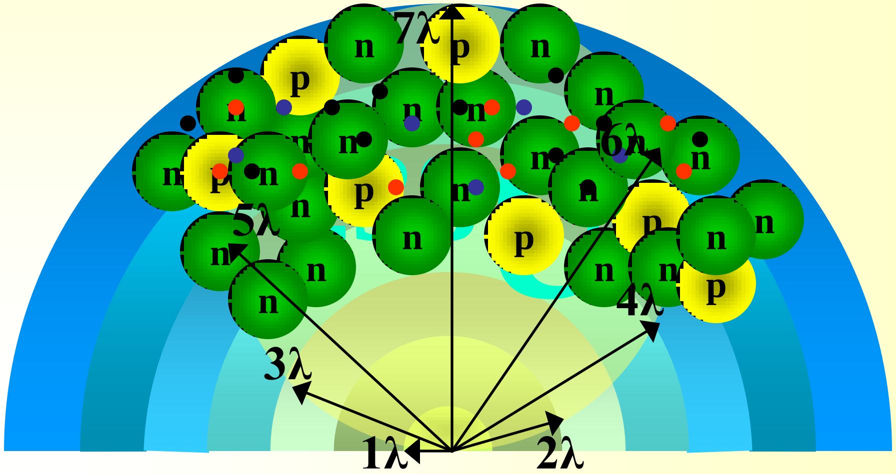
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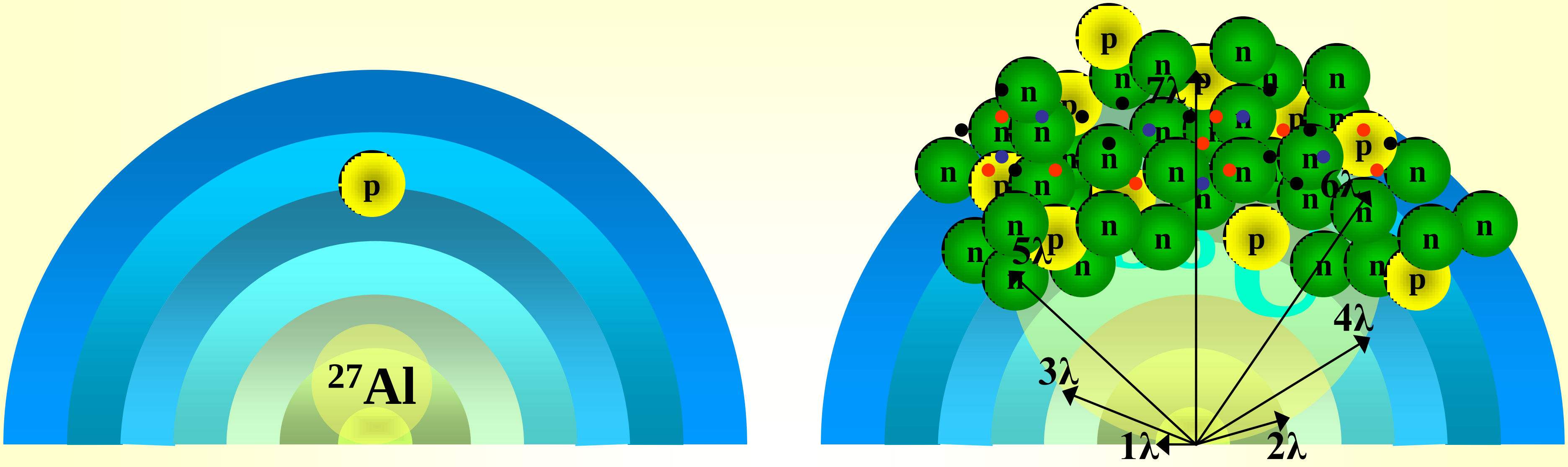
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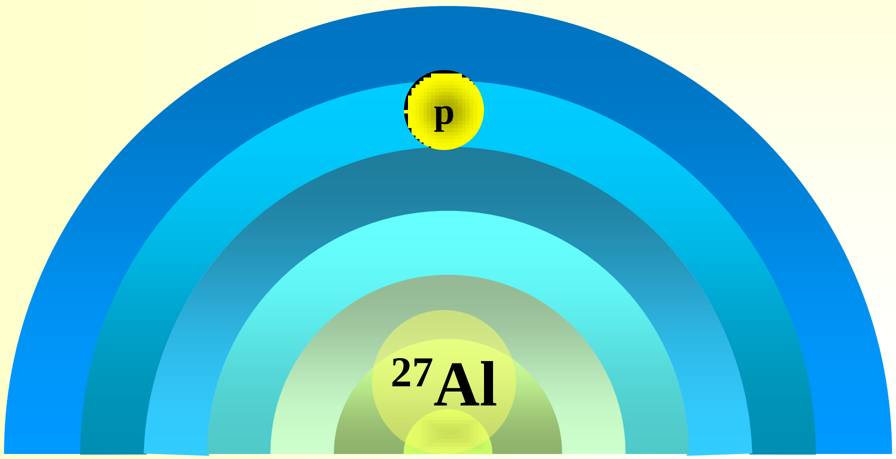
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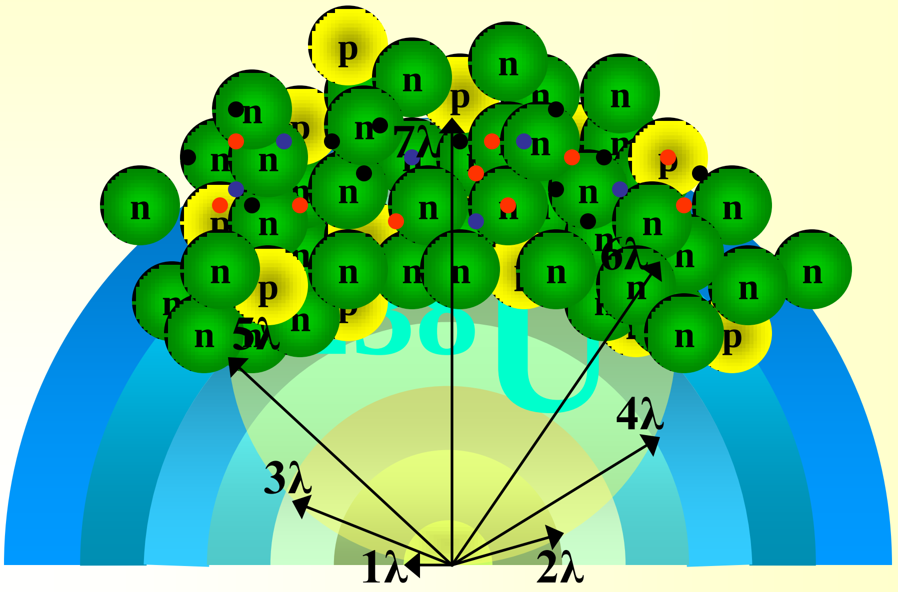
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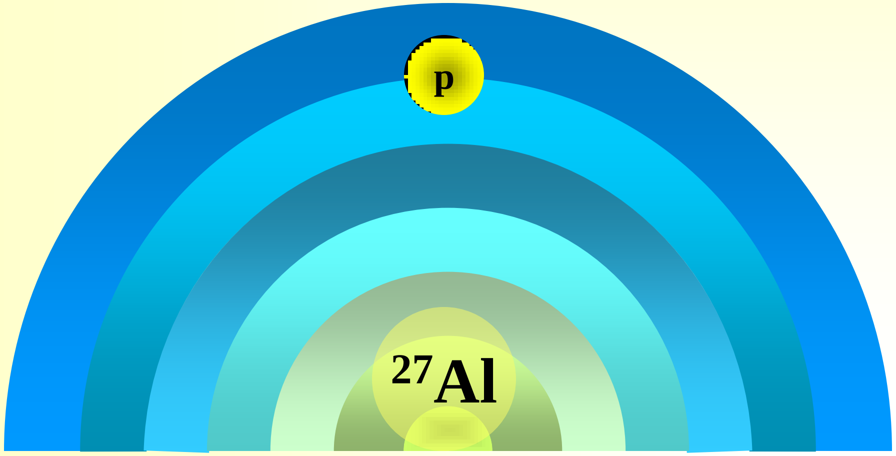
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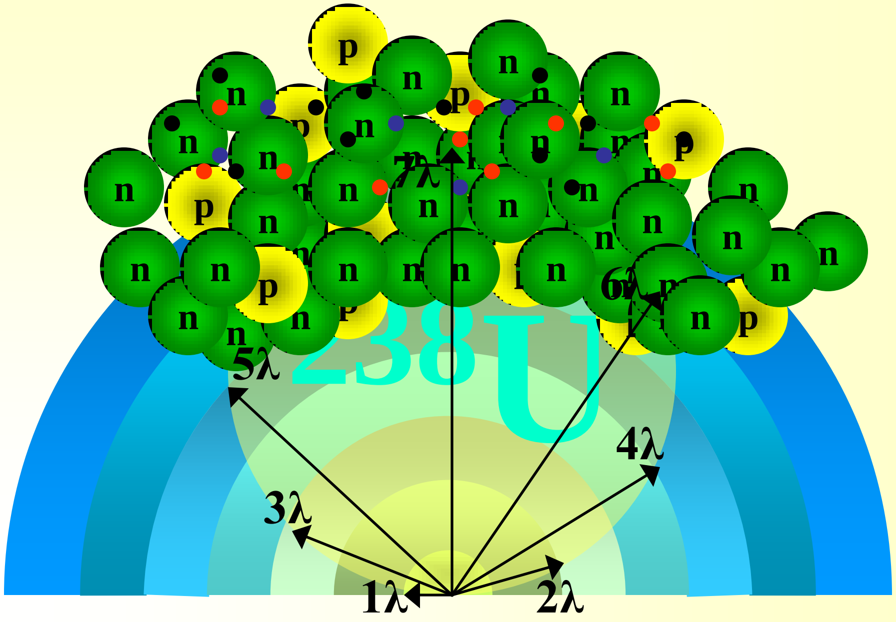
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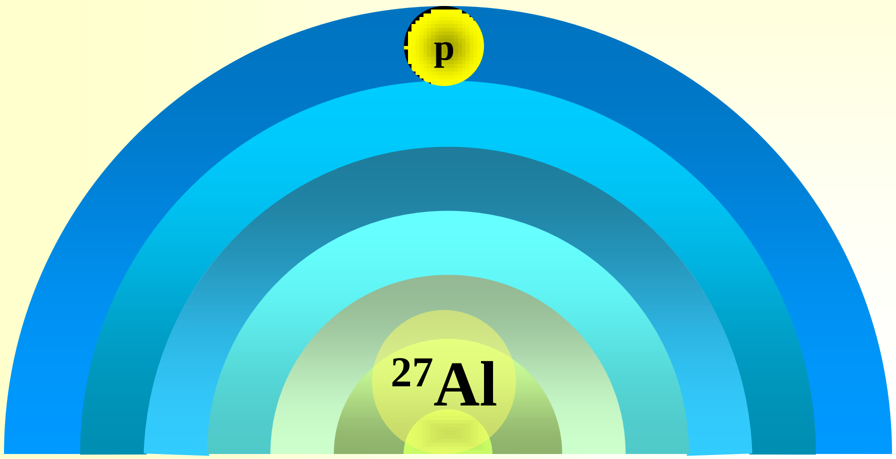
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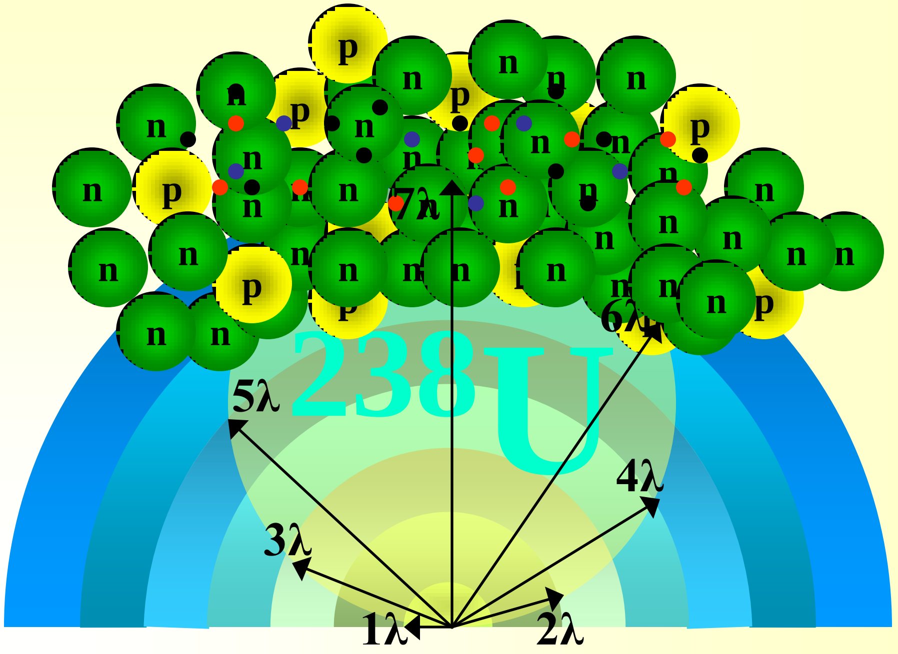
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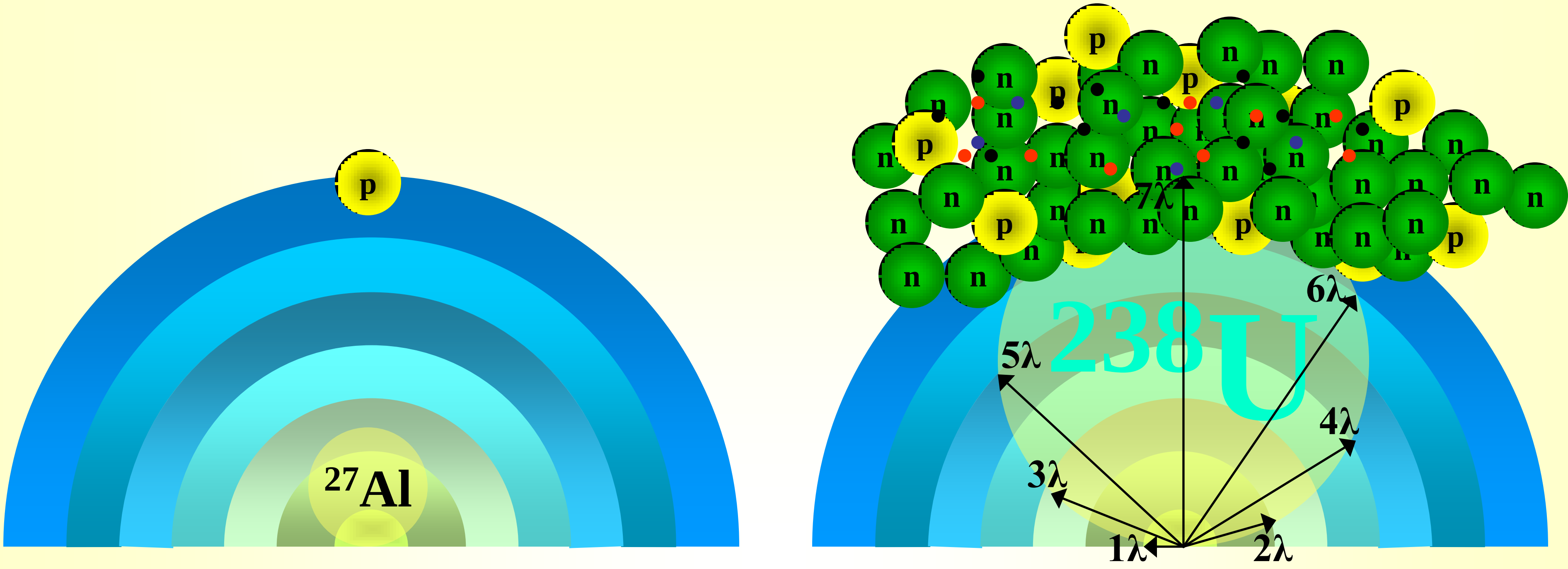

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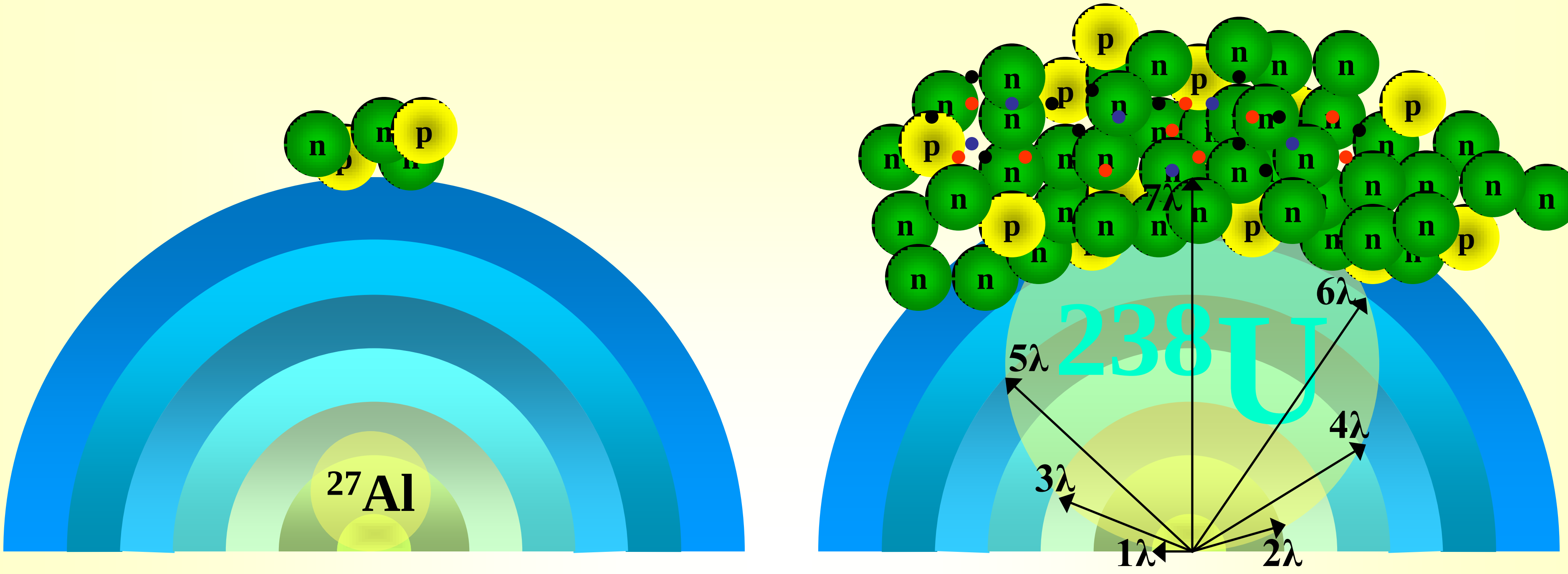
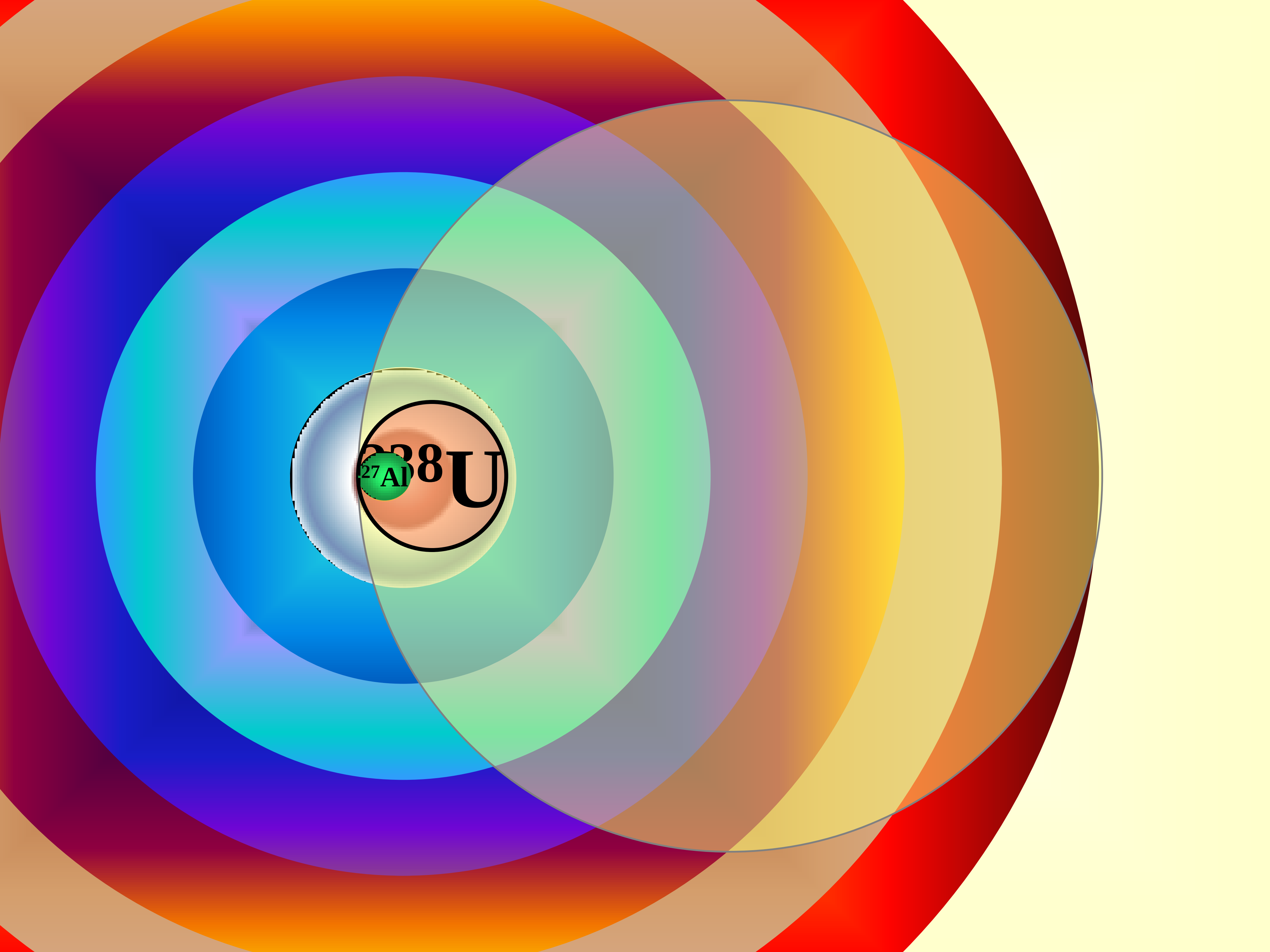
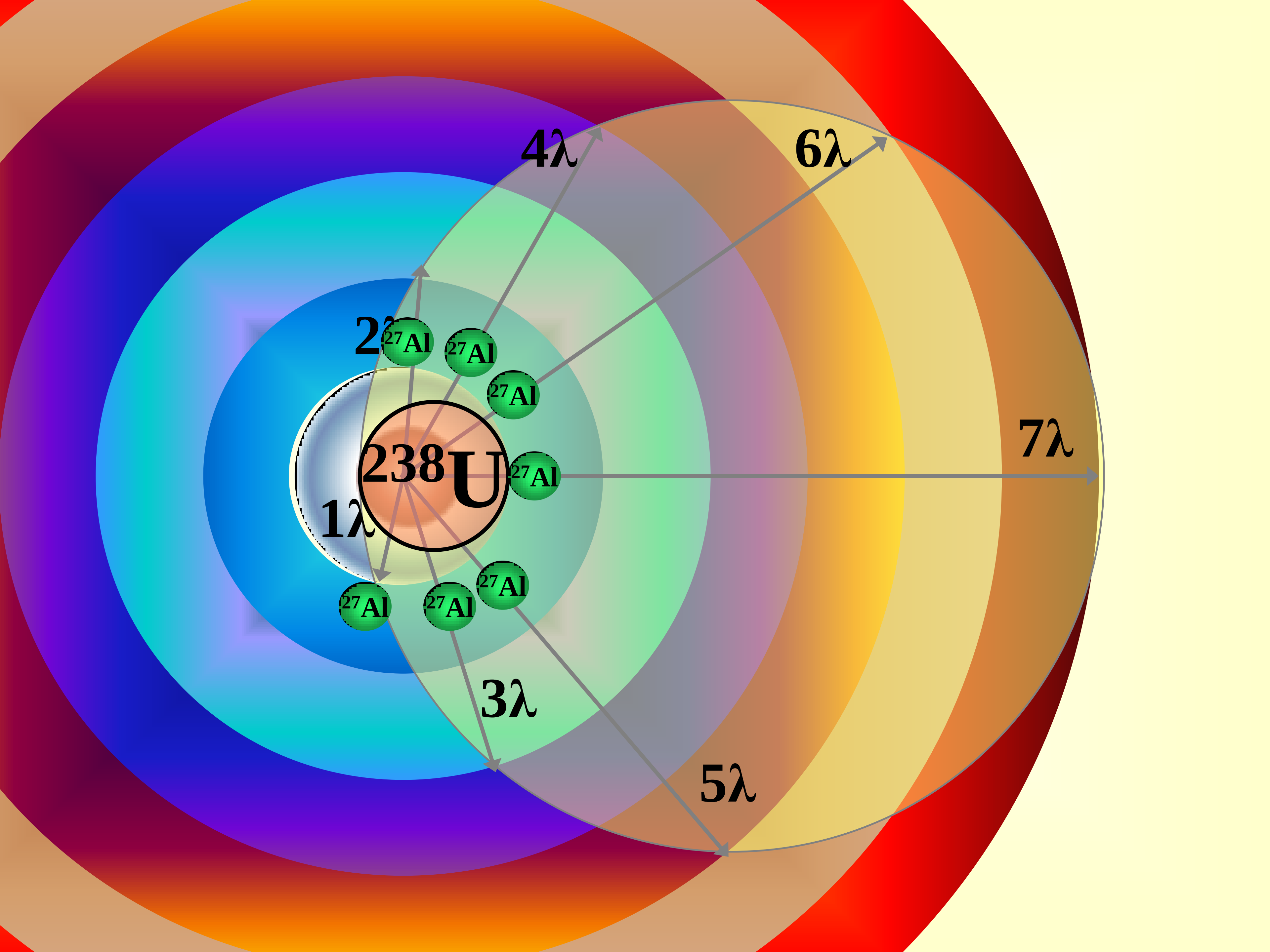


These neutrons then restore the desired multiplicity in subsequent generations of internuclear cascades


38U
27Al



4λ
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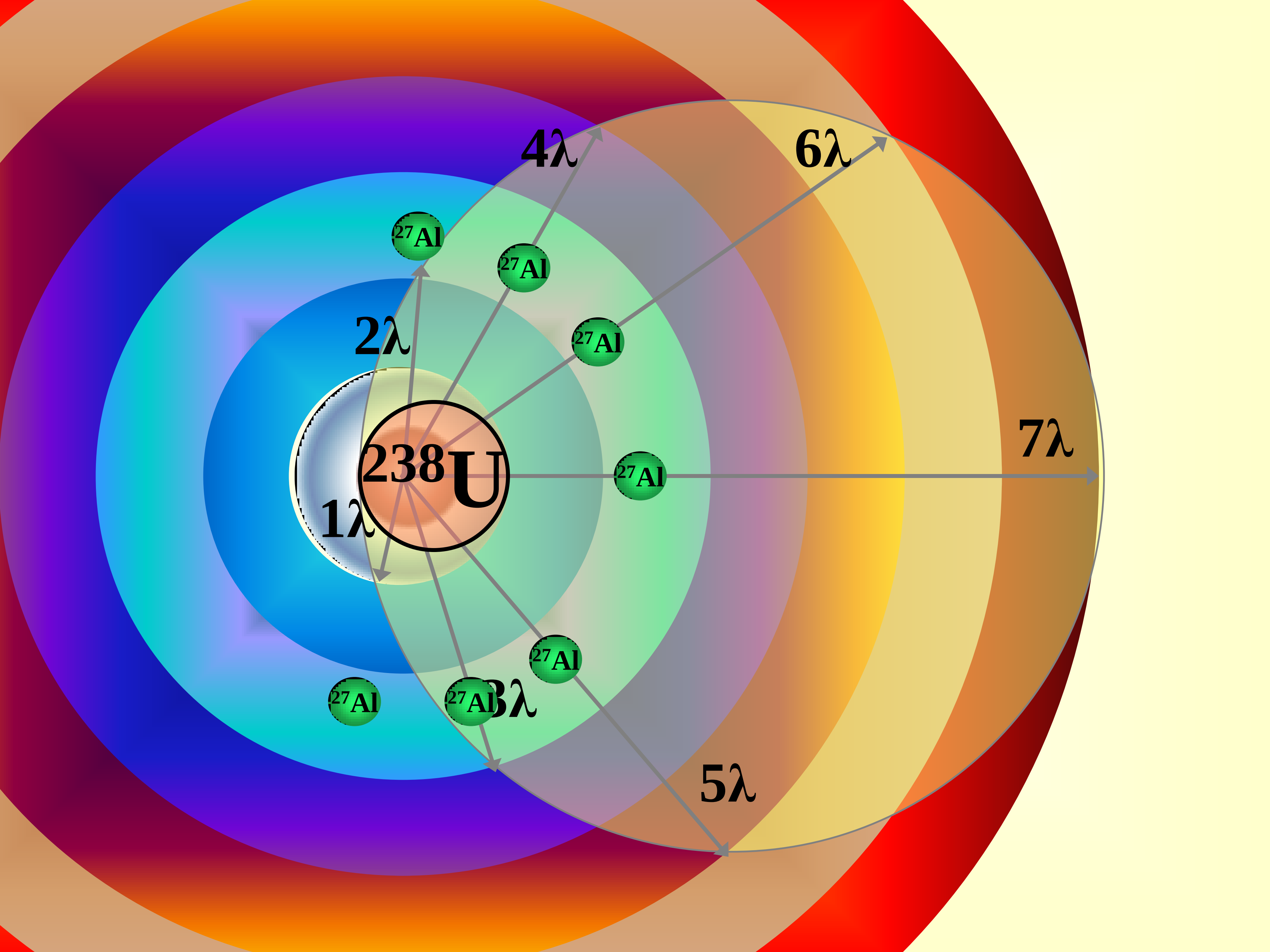
4λ
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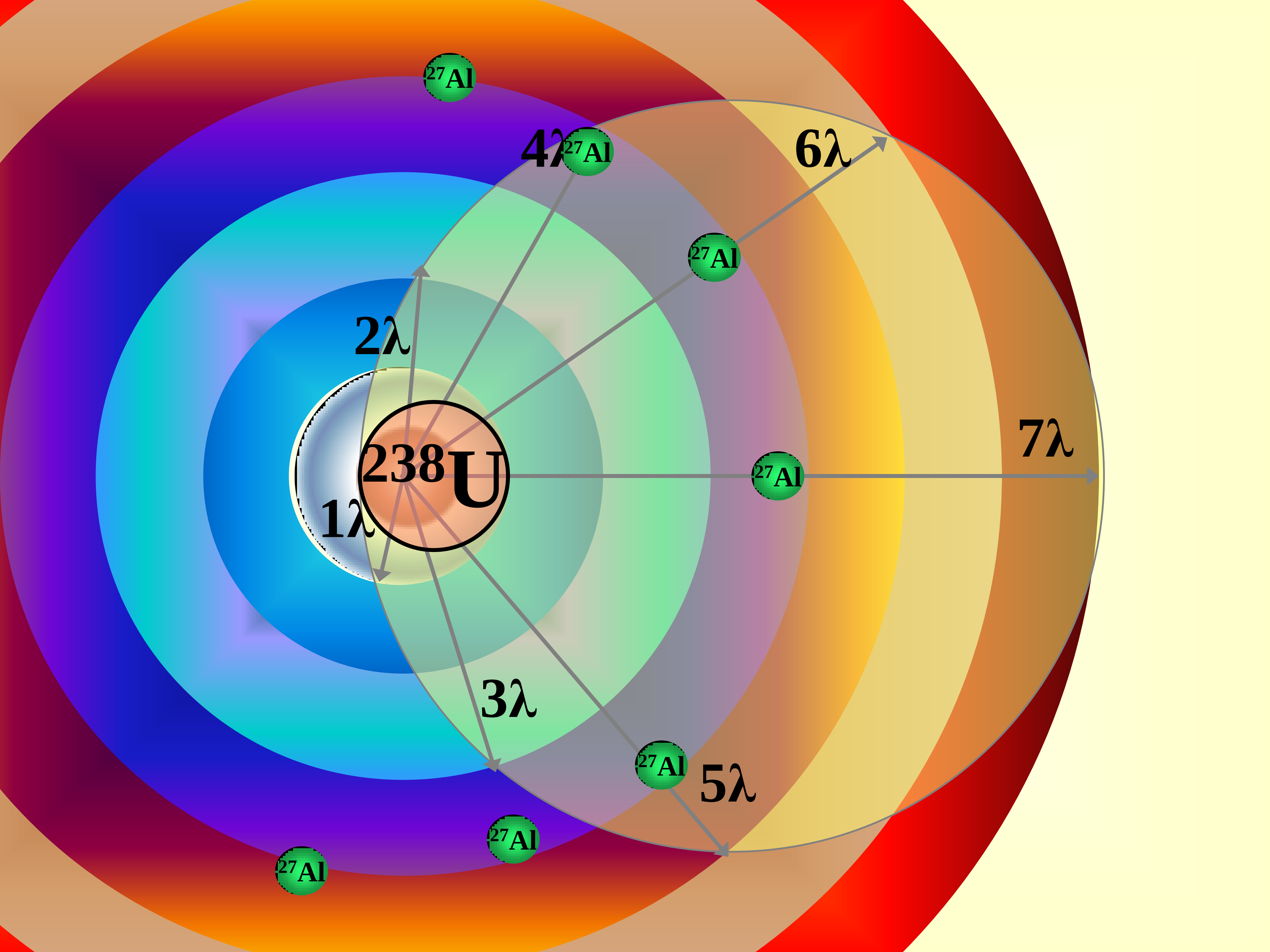

²³⁸U
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3λ
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²⁷Al
²⁷Al
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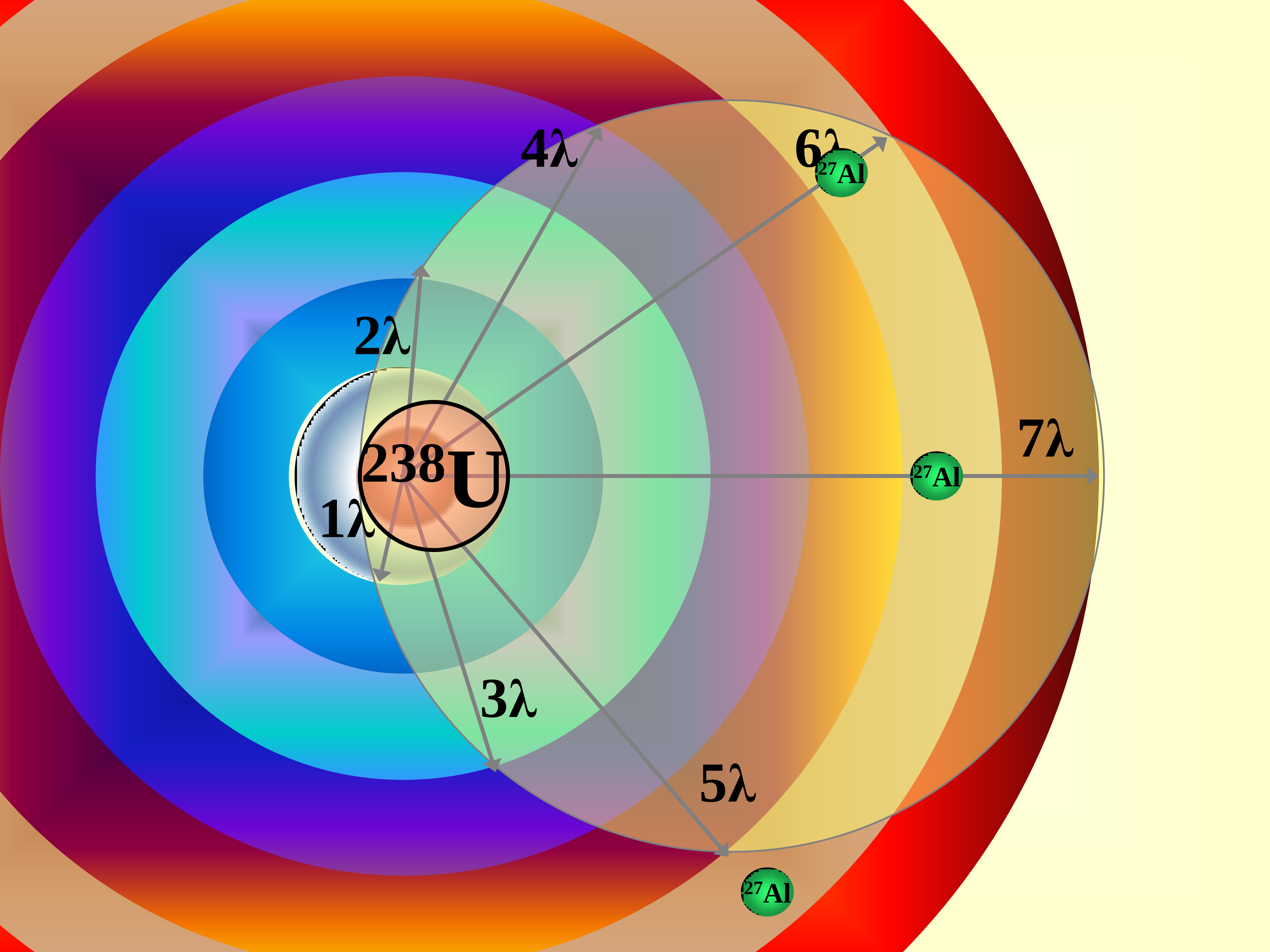
²⁷Al
²⁷Al
²⁷Al



4λ
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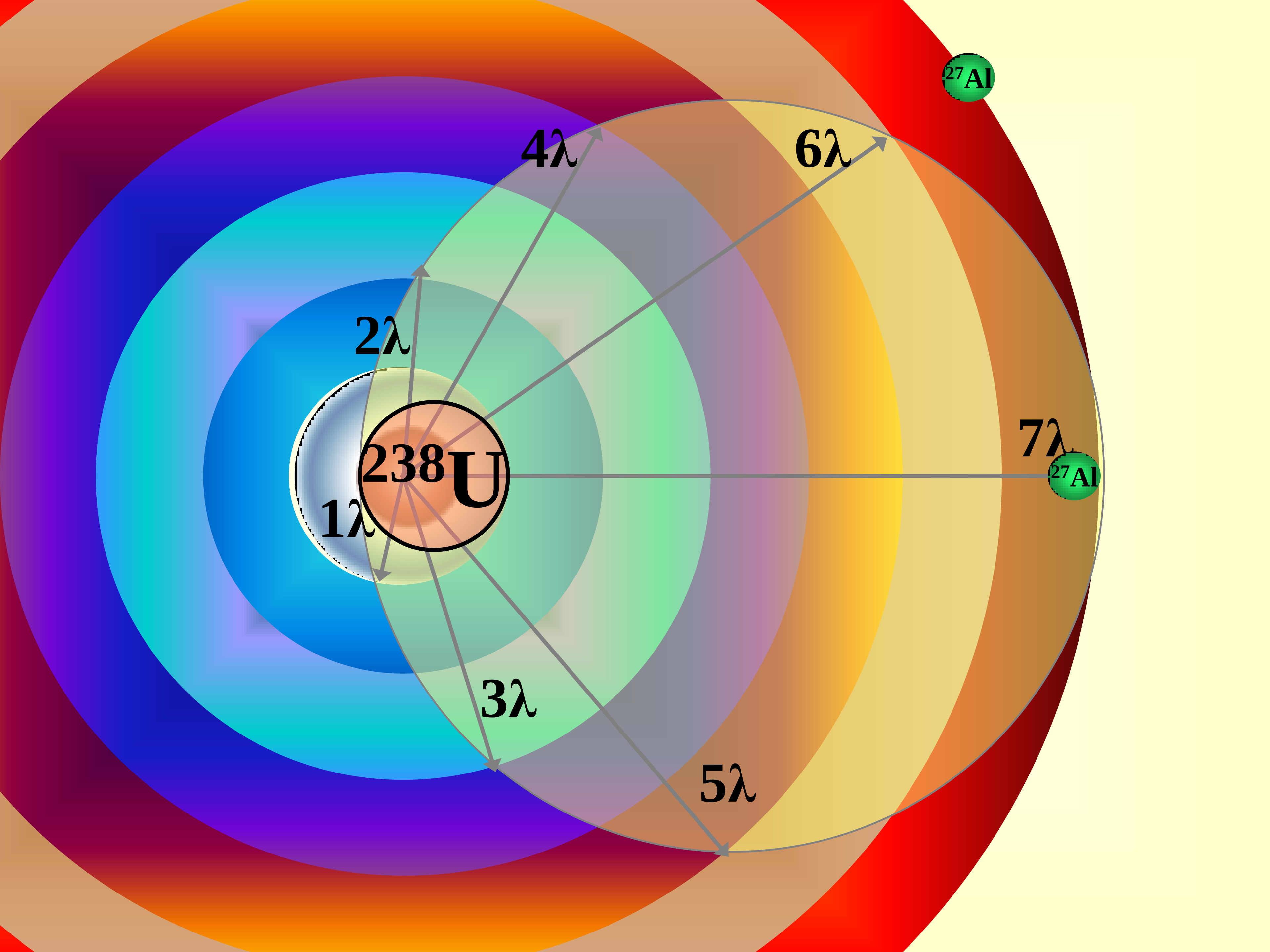
27Al



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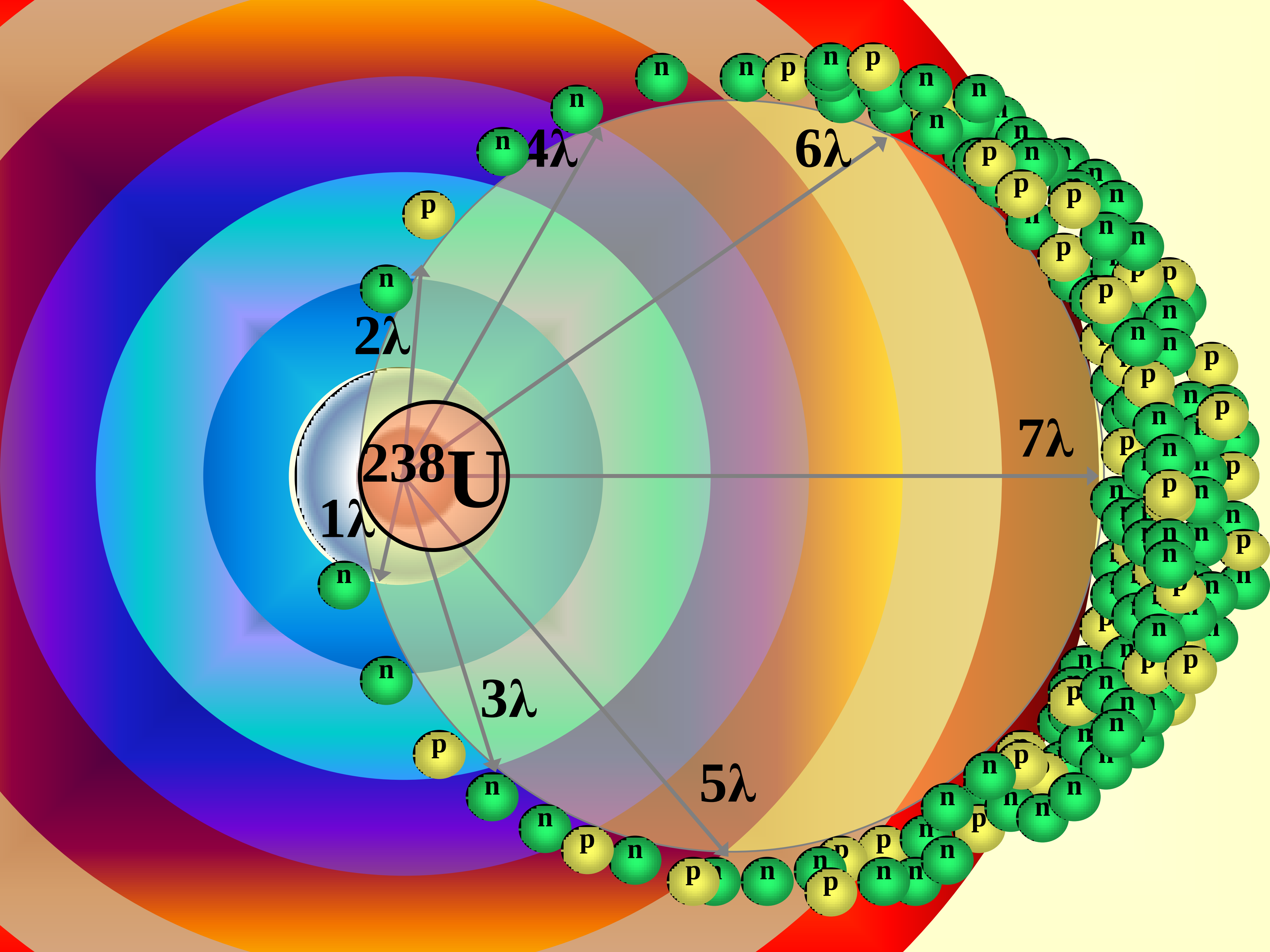
238U
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p

Advantages of RNT scheme:

- But practical application of these very perspective technologies is a subject for future serious scientific study and R&D.

- Realization of abovementioned possibilities permits to satisfy second IAEA requirement.

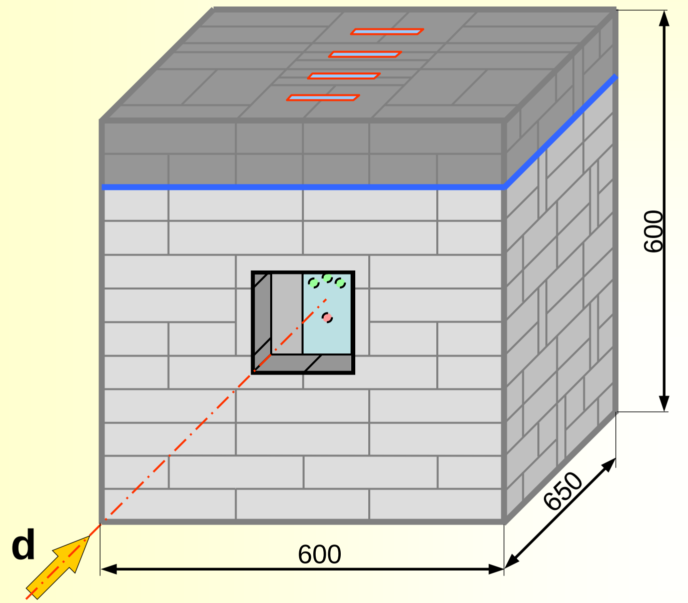
Very recently (June 2010) JINR Program advisory committee for high energy physics has endorsed the new project «Energy&Transmutation of RAW» (E&T – RAW) should be implemented on Nuclotron beam during next three years with high priority.

See J.Adam et al. **"Study of deep subcritical electronuclear systems and feasibility of their application for energy production and radioactive waste transmutation" («E&T – RAW» Collaboration), JINR Communication E1-2010-61.**

The project «E&T – RAW» is aimed at study of basic scientific feature of RNT concept. In addition, this project has serious innovation potential.

The motivation of the project research program is partly based on extrapolation of previous pioneering results obtained at JINR by groups of R. Vasil'kov et al, V. Yurevich et al and V. Barashenkov et al as well as on first essential results of measurements carried out during 2009 at JINR on Nuclotron beam and discussed below.

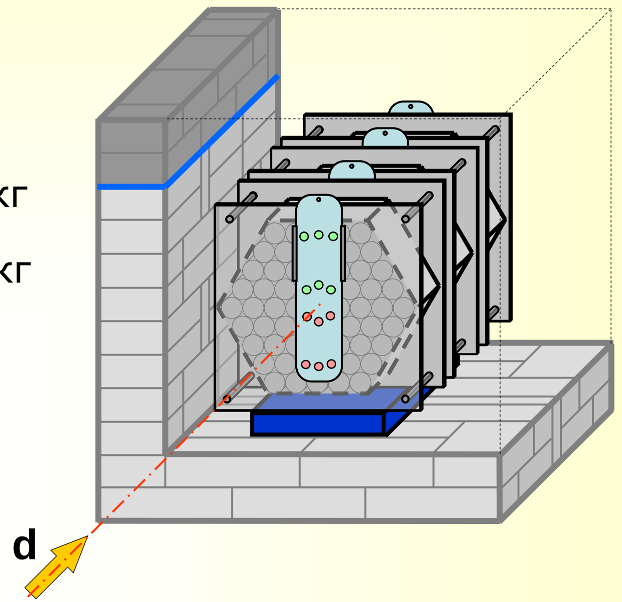
Preliminary experiments on uranium-lead assembly «Quinta» performed by JINR & Center of Physical and Technical Projects (CPTP) «Atomenergomash» in June 2009

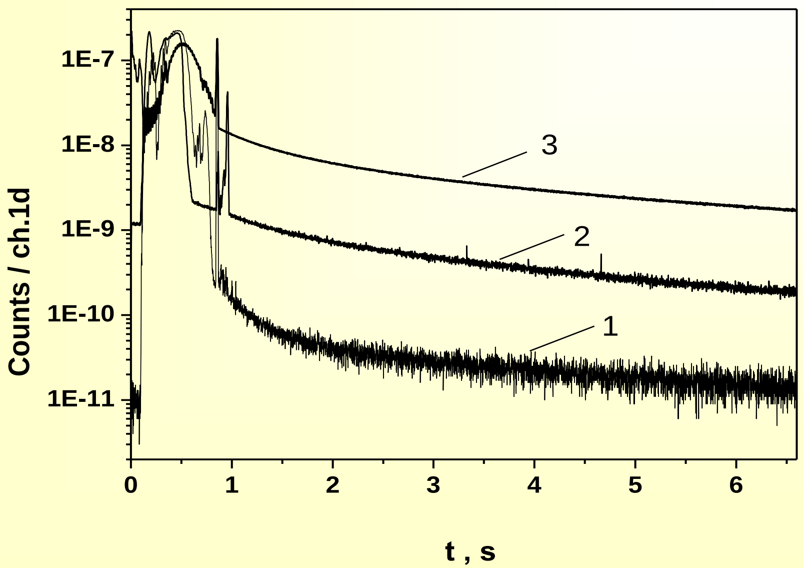


m_U= 315 кг

m_{Pb}= 1780 кг

m_Σ = 2125 кг





Time dependence of neutron yields from a geometrically identical target assemblies of lead and natural uranium (uranium mass of ~ 315 kg) irradiated by deuterons with energy of Ed = 1 and 4 GeV

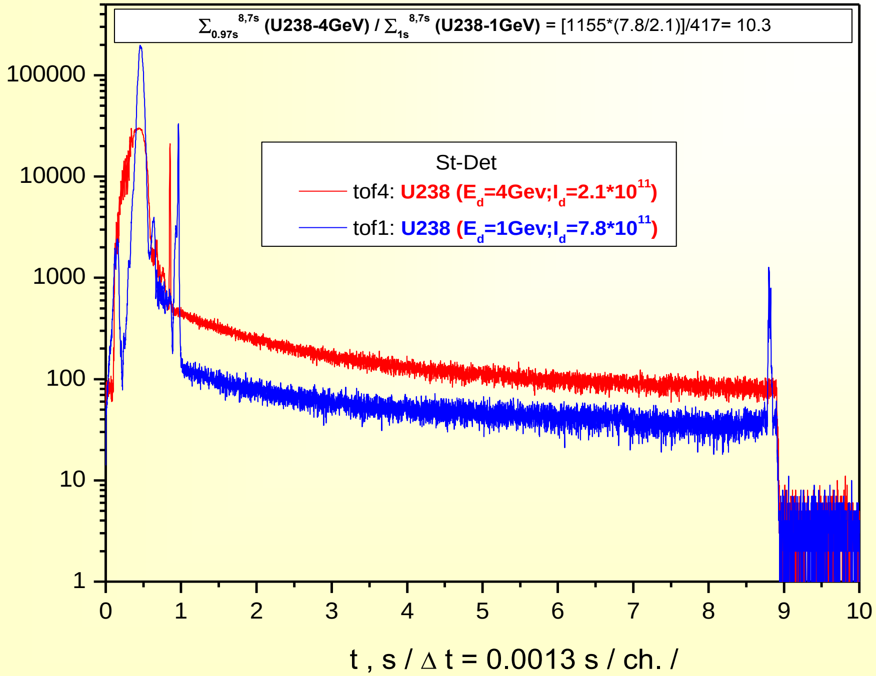
1 - (Pb + d) for E_d = 4 GeV;

2 and 3 - (U + d) for E_d = 1 and 4 GeV, accordingly.

Preliminary experiments on uranium-lead assembly «Quinta» performed by JINR & Center of Physical and Technical Projects «Atomenergomash» in 2009

Time dependent neutron spectra from assembly of ^{3}He-counters IZOMER for natural uranium target irradiated by deuterons with energy 1 and 4 GeV.

A respective increase of the fission event numbers with growing of incident beam energy consists of ~ 8,7 ± 1,2



Time dependent neutron spectra from St-detector for natural uranium target irradiated by deuterons with energy 1 and 4 GeV.

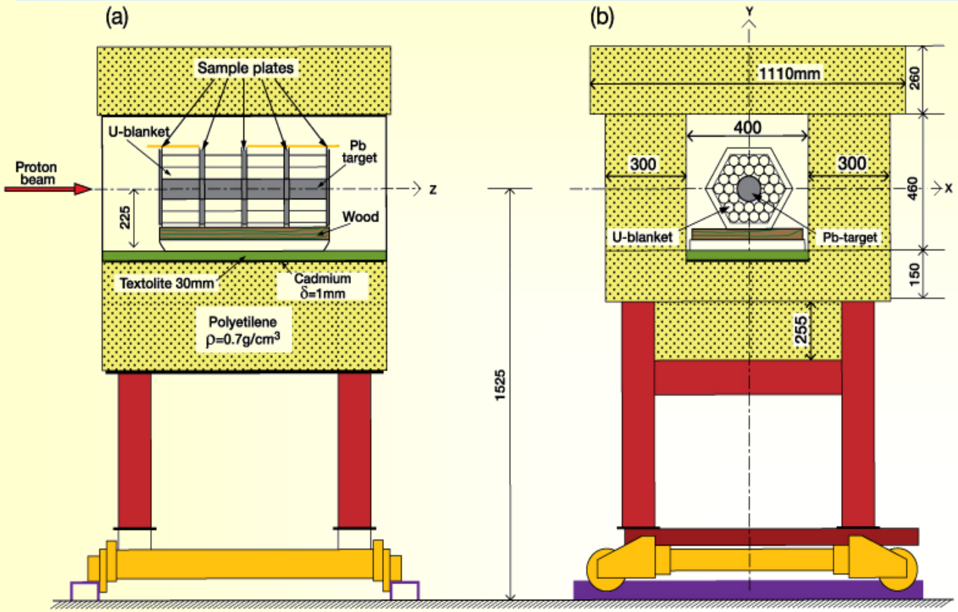
A respective increase of the fission event number with growing of incident beam energy consists of ~ 10,3 ± 1,5

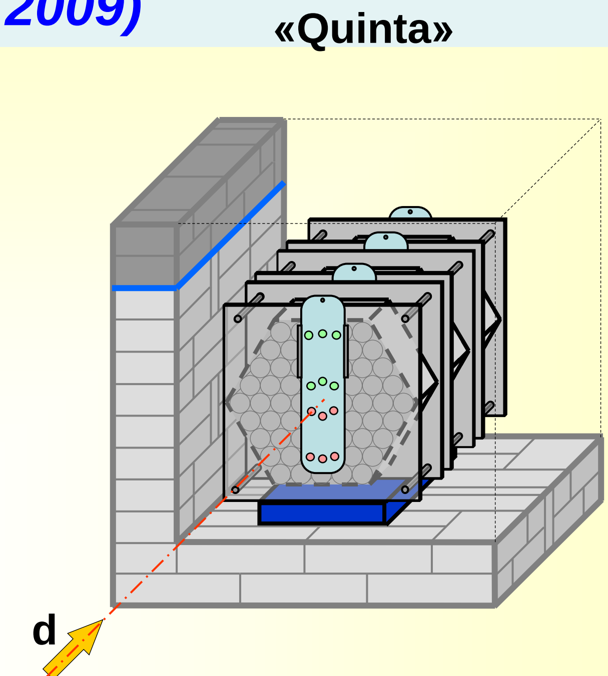
Preliminary experiments on uranium-lead assembly «Quinta» performed by JINR & Center of Physical and Technical Projects (CPTP) «Atomenergomash» in June 2009

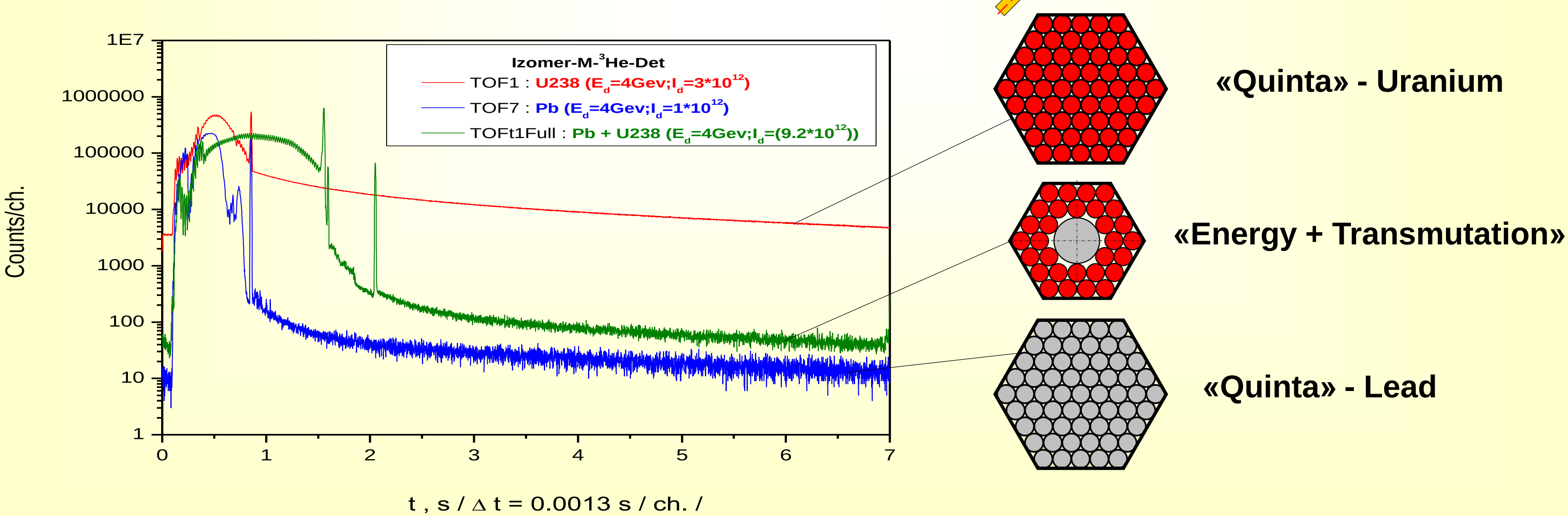
- From results shown in previous slide can be obtained the following challenging conclusion –

– the enhancement coefficient of deuteron beam power increases about two times with growing of incident energy from 1 to 4 GeV !

Measurements with target assembly «Energy + Transmutation» (E_d= 4 GeV, November 2009)



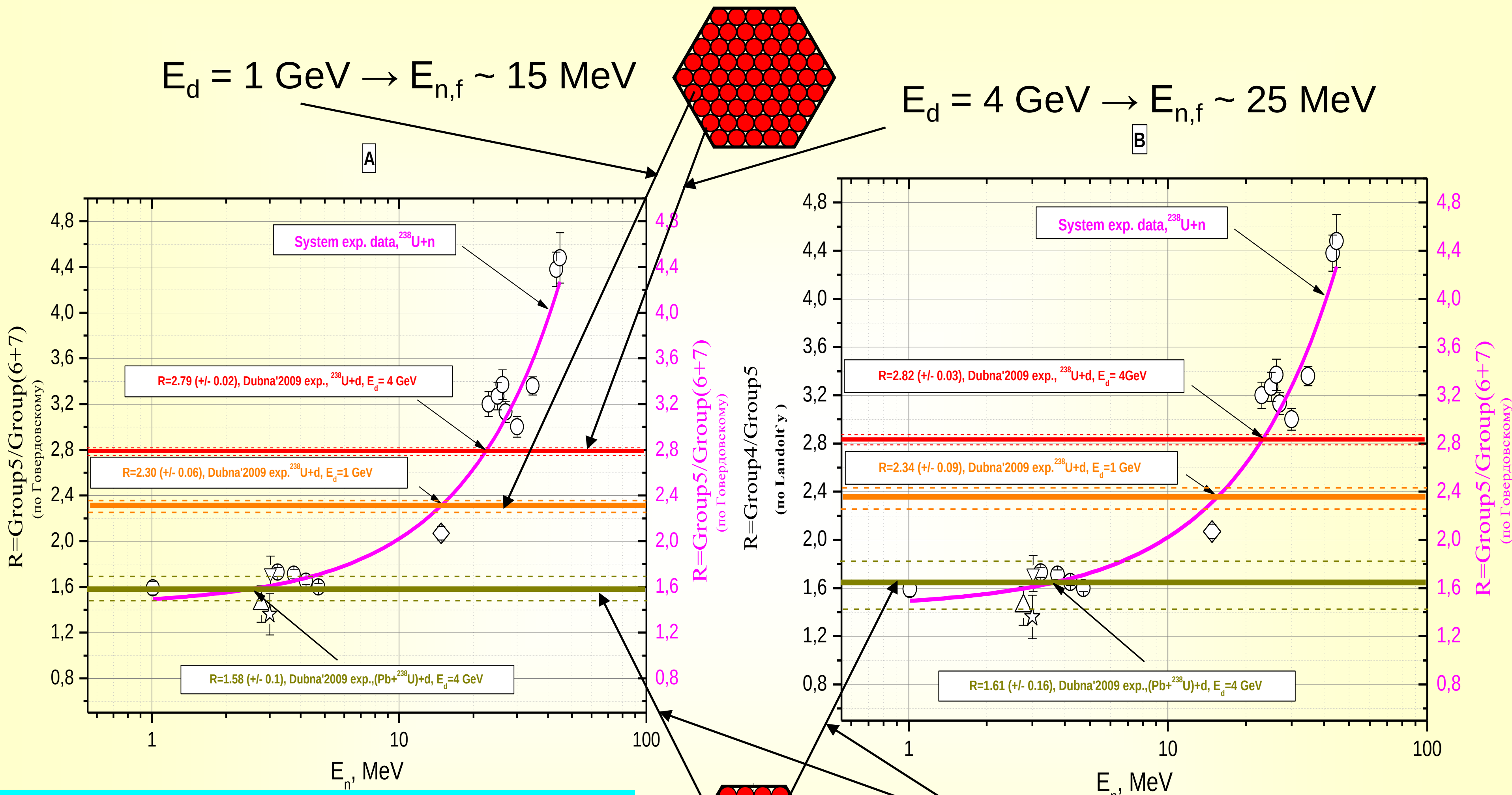




«Quinta» - Uranium

E_d = 1 GeV → $E_{n,f}$ ~ 15 MeV

E_d = 4 GeV → $E_{n,f}$ ~ 25 MeV



E_d = 4 GeV → $E_{n,f}$ ~ 3 MeV

Dependence of ratios of DN groups (5/(6+7)) **(A)** and (4/5) **(B)** from ^{238}U(n,f)-reaction on neutron energy in comparison with the same ratios extracted from our data taken in measurements with targets “Quinta” and “Energy + Transmutation”

«Energy + Transmutation»

The obtained results could have an essential influence on future of ADS development

1. For the first time it was obtained rather promising data that challenge the current understanding of the ADS system physics, namely:

a) **the optimal energy of incident beam lies near 1 GeV**;

b) **with increasing beam energy above 1 GeV power gain or falls** in accordance with the theoretical modeling **or goes to saturation** as it is shown in experiment FEAT of C. Rubbia group.

2. If confirmed, the growth gain power over a wider range (up to 10 GeV) energy of incident particles is **necessary to clarify the fundamental mechanism of this growth** through a set of experimental, computational and theoretical studies.

The results obtained by virtue of their non-triviality, of course, require more experimental confirmation.

In December of this year planned for a large set of measurements during irradiation setup "Quinta" by deuterons with energies of 2 GeV, 4 GeV, and ~ 6 GeV.

Task experiments

1. Determine the dependence of the beam power gain on the deuteron energy in the uranium target with aid of different methods and to obtain the base for extrapolation of its behaviour on case of quasi-infinite target.
2. Determine the spatial distribution of the plutonium production in the target aimed at prediction of its growth in the transition to quasi-infinite target.
3. Get a set of experimental data to test and if necessary, modify the existing cascade models and transport codes, which will improve the reliability of predicting outcomes of future experiments under the **«E&T – RAW»** project.

Additionally, in the course of the experiments setup "Quinta" will be used as a source of high-energy neutrons with a controlled spectrum for research on transmutation .

The authors express their gratitude to all those who contributed to the experimental results underlying the study of the project «E & T - RAW», and also participated in the analysis of the results and discussions of the main provisions of the present work, in particular:

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L.N. Fal'kovsky, B.I. Fonarev («Atomenergomash»).

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