Production of new neutron rich heavy and superheavy nuclei

- Fusion reactions
  - Elements 119 and 120 are on the way. What’s the next?
  - Radioactive ion beams?

- Multinucleon transfer reactions
  - Shell effects in damped collisions of heavy ions?
  - Production of new neutron rich SH nuclei in transfer reactions
  - Production of new neutron rich Heavy nuclei in transfer reactions
  - Separation of the products of transfer reaction (GALS setup)

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We are still far from the Island of Stability

\[
\text{last 30 years}
\]

\[
\text{beta - stability line}
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\[
\text{Island of Stability}
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What is beyond 118 element?

Heaviest target: $^{249}\text{Cf} \rightarrow Z_{\text{max}} = 118$

- Heavier projectiles ($^{50}\text{Ti}$, $^{54}\text{Cr}$, $^{58}\text{Fe}$, $^{64}\text{Ni}$)
- Heavier targets ($^{251}\text{Cf}$, $^{254}\text{Es}$ -???);
- Symmetric reactions: $^{136}\text{Xe} + ^{136}\text{Xe}$, $^{136}\text{Xe} + ^{150}\text{Nd}$, $^{150}\text{Nd} + ^{150}\text{Nd}$;
- Multi–Nucleon–Exchange - Reactions with RIB (??, or colliders – technique – (K4-K10));
- Nucleon transfer reactions ($^{136}\text{Xe} + ^{208}\text{Pb}$, $^{238}\text{U} + ^{248}\text{Cm}$).

Sufficient increasing of overall experiment efficiency is needed!
New elements 119 and 120 are coming!

**Ti beam:**

*TASCA (October, 2012)*

\[ ^{50}\text{Ti} + ^{249}\text{Bk} \rightarrow ^{299}\text{119} \]

\[ \sigma \sim 50 \text{ fb} \]

**Cr beam:**

*SHIP (May, 2011)*

\[ ^{54}\text{Cr} + ^{248}\text{Cm} \rightarrow ^{302}\text{120} \]

\[ \sigma \sim 25 \text{ fb} \]

Our predictions (PRC 2008): factor \( \frac{1}{20} \) as compared to \( ^{48}\text{Ca} \)

Approaching the area of instability:

*Probably, these elements are the last ones which will be synthesized in the nearest future*
Mass-energy distributions of binary reaction fragments

\[ ^{36}\text{S}+^{238}\text{U} \rightarrow ^{274}\text{Hs}^* \]
E*=46 MeV

\[ ^{48}\text{Ca}+^{238}\text{U} \rightarrow ^{286}\text{Cn}^* \]
E*=35 MeV

\[ ^{64}\text{Ni}+^{238}\text{U} \rightarrow ^{302}\text{120}^* \]
E*=31 MeV

Driving potentials are calculated with the NRV code (nrv.jinr.ru)

Yields (arb.u.)

\begin{itemize}
\end{itemize}
Influence of entrance channel

$^{22}\text{Ne} + ^{249}\text{Cf} \rightarrow ^{271}\text{Hs}$  $^{36}\text{S} + ^{238}\text{U} \rightarrow ^{274}\text{Hs}$  $^{58}\text{Fe} + ^{208}\text{Pb} \rightarrow ^{266}\text{Hs}$

$E_{\text{CN}}^* = 52 \text{ MeV}$  $E_{\text{CN}}^* = 56 \text{ MeV}$  $E_{\text{CN}}^* = 48 \text{ MeV}$

$E_{\text{CN}}^* = 29 \text{ MeV}$  $E_{\text{CN}}^* = 35 \text{ MeV}$  $E_{\text{CN}}^* = 33 \text{ MeV}$

$Z1Z2=980$  1472  2132  2660

$^{88}\text{Sr} + ^{176}\text{Yb}$: shell effects in damped collisions

Fusion reactions with Radioactive Ion Beams for the production of neutron rich superheavy nuclei?

No chances today and in the nearest future.
Multinucleon transfer reactions for synthesis of heavy and superheavy nuclei
Production of superheavies in multi-nucleon transfers (choice of reaction is very important)
Shell effects: Pb valley

normal (symmetrizing) quasi-fission

inverse (anti-symmetrizing) quasi-fission
U-like beams give us more chances to produce neutron rich SH nuclei in “inverse quasi-fission” reactions.

Experiment is scheduled for March at GSI (we want to see Pb+x, then Pb+Ca+Pb)
$^{238}\text{U} + ^{248}\text{Cm}$. Primary fragments

$^{238}\text{U} + ^{248}\text{Cm}$, $E_{\text{c.m.}} = 780$ MeV
primary fragments
Production of transfermium nuclei along the line of stability looks quite possible (only if there are shell effects!?)

Rather wide angular distribution of reaction fragments: a new kind of separators is needed

Experiments on Au+Th and U+Th are currently going on in Texas (without separators)
Test (surrogate) reaction aimed on a search for the shell effects in low-energy multi-nucleon transfer reactions.

The experiment was performed (September 2014) at the Flerov Laboratory (Dubna).

VZ and Greiner, 2007

radio-chemical experiment: W. Loveland, 2010

gain owing to shell effects

The experiment was performed (September 2014) at the Flerov Laboratory (Dubna)
New heavy nuclei in the region of $N=126$

proton transfer along the neutron closed shells:

$$^{136}_{N=82}Xe + ^{208}_{N=126}Pb \rightarrow ^{136+\Delta Z}_{N=82}X + ^{208-\Delta Z}_{N=126}Y + Q \approx 0$$

Reactions with $Q \approx 0$ are very favorable for proton transfer. The use of $^{132}Sn$ is even better!

Several tens of new neutron-rich nuclides can be produced with cross section higher than one microbarn in the near-barrier collision of $^{136}Xe$ with $^{208}Pb$. 
Test experiment on $^{136}\text{Xe} + ^{208}\text{Pb}$ collisions (Dubna, 2011)

Experiment with Z identification of PLF was performed in Legnaro last summer
$^{136}$Xe$+^{208}$Pb: productions of heavy neutron-rich nuclei in multinucleon transfer reaction

$^{136}$Xe$+^{208}$Pb ($E_{\text{c.m.}} = 526$ MeV)

Cross section for $^{210}$Po, $^{222}$Rn, $^{224}$Ra (Activation analysis)

$^{136}$Xe$+^{208}$Pb ($E_{\text{c.m.}} = 514$ MeV)


Production of new neutron rich heavy nuclei located along the last “waiting point” of astrophysical nucleosynthesis: Choice of reaction?
How to separate a given nucleus from all the other transfer reaction products?

Available separators are not applicable!
New setup for selective laser ionization and separation of multi-nucleon transfer reaction products stopped in gas

*(project GaLS, to be realized in Dubna in 2015)*
New setup for selective laser ionization (FLNR, Dubna)

two pumping lasers Nd: YAG and three DYE lasers (+ Ti: Sapphire laser)
Summary

- Elements 119 and 120 can be really synthesized in the Ti and/or Cr fusion reactions with cross sections of about 0.05 - 0.02 pb.

- Multi-nucleon transfer reactions can be really used for synthesis of neutron enriched long-living SH nuclei located along the beta-stability line. U-like beams are needed as well as new kind of separators.

- Shell effects in production of trans-target nuclei (inverse quasi-fission) should be proved experimentally at last.

- Transfer reactions give a unique possibility for synthesis of heavy neutron-rich nuclei with N=126 – the last “waiting point” of astrophysical nucleosynthesis.

- Selective laser-ionization technique (GALS setup being developed at FLNR) is a powerful method of separation of the products of transfer reactions.