CONCLUSION

By its very nature nuclear trafficking is a transboundary problem; nuclear materials may be manufactured in one location, diverted at a second location, and detected at a third. By encouraging the participation of those states where nuclear materials are interdicted, the ITWG brings nuclear forensics expertise and capabilities closer to the states affected by these cases. Only by sharing information about nuclear processes and materials can participants benefit from collective experience and knowledge to evaluate and prosecute nuclear trafficking cases. Exchange of forensic databanks of information and collaboration in the international nuclear forensic enterprise will resolve cases faster and with greater confidence. Through a common approach to the problem and the ability to draw on international experience, the ITWG is a significant force in the fight against illicit nuclear trafficking.

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FUTURE COORDINATED RESEARCHES BY ARGONNE (USA), TASHKENT (UZBEKISTAN) AND ALMATY (KAZAKHSTAN) NUCLEAR CENTRES ON THE NUCLEAR REACTIONS AND ASTROPHYSICS

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Main points of the report:

- Problems and Methods used for study of the nuclear astrophysical reactions
- Activity of scientists of the three Institutions in this field
- Experimental possibilities of these institutions
- Nuclear Astrophysics reactions which would be studied.

I. PROBLEMS OF NUCLEAR ASTROPHYSICS

An actual problem of modern nuclear astrophysics is realistic evaluation of astrophysical S-factors and rates of the nuclear reactions, which is responsible for the energy generation and nucleosynthesis in universe at different stages of its evolution. Essential progress in understanding some of these processes has been made in the last decade [1-4]:

-development of the indirect methods for obtaining astrophysical relevant data;

-using Radioactive Ion Beams and inverse kinematics in measurements;

-development of methods of cross section extrapolation to the stellar energy region.

Remarkable amount of new data on the reaction cross sections at low energies have been obtained now (see for example [3,4]) and steady progress achieved in reevaluation the rates of different nuclear processes that are a way of nucleosynthesis and source of energy generation in the universe. But, in spite of the considerable progress in accumulation of the necessary information, the available experimental data, close to stellar energies, are insufficient, especially for unstable particle interactions. The uncertainties, connected both with the experimental errors and extrapolation of measured cross sections to the low energy region, remain rather remarkable. It influences the model predictions for the production of elements and energy generation in quiescent and explosive stellar nucleosynthesis [5].

The research in this field is pursued at many nuclear physical centers in the world including INP AS RUz and INP NNC RKaz. Such investigations are also carried out at ANL (USA).We now are looking forward to coordinate the research of three scientific groups in these institutions in the field of nuclear astrophysics. The experimental possibilities of the "ATLAS" facility, at the U-150M and UKP-II accelerators will be used as well as some new approaches for obtaining the astrophysical *S*-factors and reaction rates.

What nuclear data are needed for nuclear astrophysics now? Firstly, there are precise astrophysical *S*-factors and reaction rates. The critical stellar features (energy production, nucleosynthesis, etc.) depend directly on the magnitude of the reaction rate per particle pair $<\sigma\upsilon>$ which is defined by the relative probability of the process. As one can see from the Figure 1 (taken from [6]) that for the normal stellar gas this value has a relatively narrow energy peak around the effective burning energy E_0, the so-called «Gamow window». It is situated within approximately $40\div120$ keV ($T{\sim}2\times10^7\div5\times10^7$ K) for hydrogen burning, and ${\sim}80\div450$ keV ($5\times10^7\div3\times10^8$ K) for helium burning.

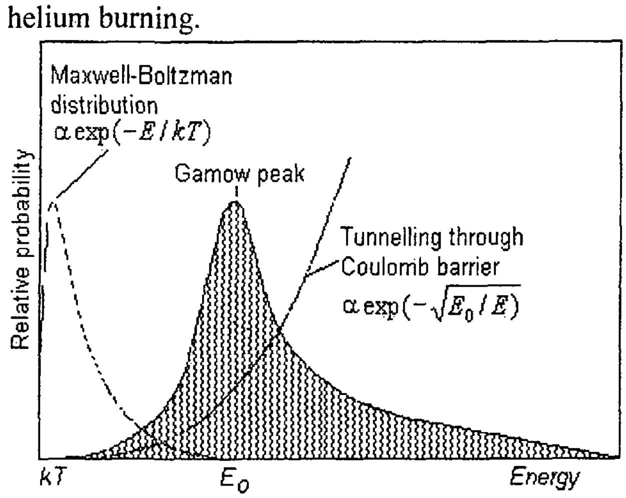

Fig. 1. Relative probability as a function of the charged particle energy.

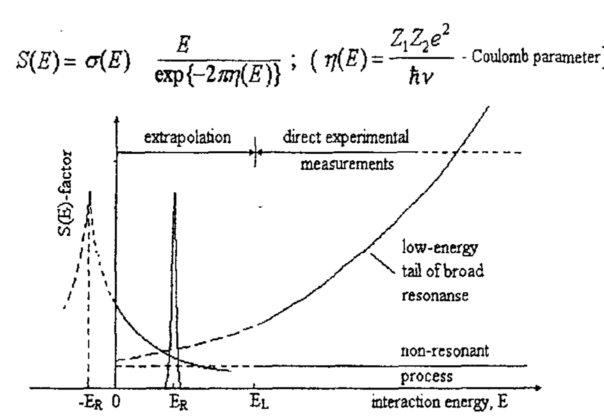

Fig. 2. Astrophysical *S*-factor's behavior [6].

The achieved lower boundary of the energy in the laboratory measurements is marked as E_L in Figure 2. Therefore extrapolations from higher laboratory energies to lower stellar energies are needed.

The astrophysical *S*-factor is commonly used, which (in contradiction to the cross section which drops exponentially) is a smoothly varying function of energy, so the advantage of its use is obvious. Commonly the *S*(0) values are obtained and tabulated. However, the "*E* equal zero" limit is disadvantageous compared to the more natural effective-energy limit. The latter is used in order to modify the thermonuclear reaction rate formula in stellar evolution codes so that it takes into account both plasma and laboratory screening effects.

As one can see from the figure, several processes can contribute to the S-factor (or cross section), namely, the direct reaction component, broad resonances at higher energies, or at lower energies (including the extrapolation region), and even below the reaction threshold as well as their interferences. To take all these phenomena into account, the exact knowledge of reaction mechanism as well as the spectroscopic data and the resonance parameters (spin and parity J^{π}, strength, level widths, etc.) is necessary.

II. METHODS OF OBTAINING DATA

Below we mention briefly two possibilities of the «laboratory» investigations of nuclear astrophysical reactions which in use now. They are called as «direct» and «indirect» methods, respectively.

Direct methods. These are laboratory measurements of the same reactions which occur in astrophysical processes within the Gamow window or at somewhat higher energies. Direct measurements are usually performed by using high intensity low-energy beams of the lightest nuclei (for example, hydrogen and helium ions). But also heavy ion beams including radioactive ones are now widely used. In order to reduce the relative kinetic energy, the measurements are performed in inverse kinematics with heavy projectiles and light targets.

For reducing the uncertainties behind the extrapolation procedure, difficult problems associated with background suppression, use of thin target thickness etc. shave to be solved when direct measurements are used. Nevertheless, such measurements of cross sections in the subnanobarn region are carried out at many nuclear centers.

Indirect methods. These methods measure cross sections, astrophysical S-factors and reaction rates indirectly by a nuclear reaction such as a particle transfer reactions, the «Trojan horse» method and Coulomb dissociation. The advantage of these methods is that the interaction energies are relatively large (~tens MeV/N), so that precise input data can be obtained. A disadvantage is a necessity of some model assumptions for the astrophysical cross section obtained from the data which increases the uncertainty of the extracted information. Below we enumerate some of them.

i). **Coulomb dissociation** [7,8] is extensively applied to the investigation of astrophysical processes. To study the radiative capture reaction A(x,γ)B the nucleus B bombards a high-Z target and decays onto two fragments A and x. Since the process is regarded as absorption of a virtual phonon, i.e. B(γ,x)A, the radiative capture (the inverse of the photo absorption) cross section can be extracted from the dissociation yield.

ii). **«Trojan horse» method** [9,10] is based on the quasi-free reaction mechanism, which allows one to derive indirectly the cross section of a two-body reaction A+x→C+c from the measurement of a suitable three-body process A+a→C+c+b. The effective energy of the reaction between A and x should be relatively small

iii). **Particle transfer reactions using** (ANC method) [11-17]. This method is discussed in more detail. The technique of Asymptotic Normalization Coefficients (ANC) provides an effective method of indirect determination of the "direct capture part" of S-factors for the astrophysical important reactions of particle capture A+a→B.

The ANC for the nuclear system A+a→B (or the nuclear vertex constant (NVC) of particle x virtual separation) specifies the amplitude of the tail of the overlap function of the bound state B. The ANCs can be extracted from differential cross sections of the peripheral particle transfer reactions. It should be noted that ANCs obtained from the analysis of direct transfer reactions depend very weakly on model parameters in contrast to commonly used spectroscopic factor.

The experimental differential cross section for the reaction A(x,y)B, x={y+a}, {B=A+a} (which is proposed to be a peripheral reaction) is calculated by the relations:

$$\sigma^{\text{exper}}(E,\theta) = (C_{A+a})^2 R_{b_{A+a}}(E,\theta) \tag{1}$$

$$R_{b_{A+a}}(E,\theta) = (C_{y+a})^2 \sigma^{DWBA}(E,\theta)/(b_{y+a} b_{A+a}) \tag{2}$$

Here C_{A+a}, and C_{y+a} are the ANCs for {B→A+a} and {x→y+a} configurations, b_{A+a}, b_{y+a} are the model (single particle) ANCs (obtained by the "well depth" procedure, using Woods-Saxon potentials.)

That is to say the cross section for direct peripheral reaction is calibrated by the product $(C_{y+a})^2 \times (C_{A+a})^2$.

The peripheral character of the reaction is checked by the conditions [12,13]:

1). $R_{b_{A+a}}(E,\theta_{peak}) = const$ for $\{r_0, a_{diff}\}$ within "physically reliable" intervals,

2). $(C_{A+a})^2 = \sigma^{\exp er}(E,\theta_{peak}) \Big/ R_{b_{A+a}}(E,\theta_{peak}) = const$ at E values where the stripping mechanism is dominant. The cross section $\sigma(E)$ for the direct radiative capture has the form

$$\sigma(E) = N\left|\left\langle I_{Aa}(\mathbf{r}_{Aa})\middle|O(\mathbf{r}_{Aa})\middle|\Psi_{\mathbf{k}}^{(+)}(\mathbf{r}_{Aa})\right\rangle\right|^2, \tag{3}$$

where $O(r_{Aa})$ – is the electromagnetic transition operator, $\Psi_{\mathbf{k}}^{(+)}$ - is the scattering wave function of the colliding particles A and a. For the peripheral A(a,γ)B reaction the radial overlap integral is replaced by its asymptotic expression which is calibrated by the ANC for the $B \rightarrow A+a$ system.

What reactions are suitable for the ANCs method? It is clear that first of all the reactions with loosely bound transferred particles should be taken into consideration because the reactions are expected to be peripheral. The reaction A(^{3}He,d)B is often used [14-16] for obtaining the ANC B→A+p since the energy of proton separation $\varepsilon_{3He \rightarrow d+p}$=5.49 MeV is not large and the ANC ^{3}He→d+p is well known. An additional advantage is that the outgoing particle has not the excited states.

III. EXPERIMENTAL FACILITIES OF THE INSTITUTIONS

Experimental set-up at the cyclotrons U-150-II INP AS RUzb (Tashkent) and the isochronous cyclotron U-150 M INP NNC RKaz (Almaty). Accelerated particles in these machines: ^{1,2}H+ and ^{3,4}He++ at the energies: ~8÷15 MeV/nucleon.

A new experimental set-up (by analogy with the Tashkent set-up) has recently been installed at the U-150-M (Almaty) accelerator ion line. It has been designed and manufactured jointly by Tashkent and Almaty experimentalists. Both set-ups are intended for the detection of charged particles – products of nuclear reactions.

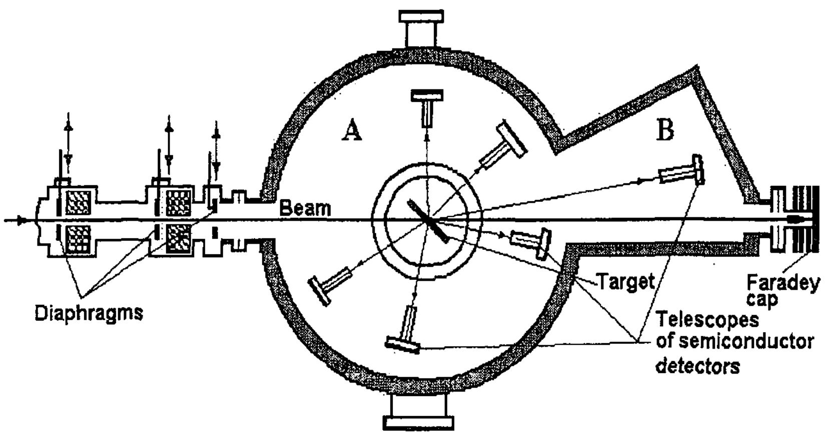

Fig.3. INP AS (Tashkent) reaction chamber for the study of (p,n,α) transfer reactions [19].

They include:
- a reaction chamber of special design equipped with the necessary automatic devices including three holders with five ΔE-E telescopes of semiconductor detectors which are moved by stepping motors;
- necessary electronics and software for identification and treatment the accumulated spectra.

Differential cross sections of the particle transfer reactions can be measured of the angular region at 2° - 176° with an accuracy 6÷8%.

Experimental set-up at the INP NNC RKaz for the measurement of nuclear astrophysical reactions by the direct method.

It is based on the electrostatic charge-exchange accelerator UKP-2-1. It has two beam lines for beam transportation (see Fig. 4.). This peculiarity is very useful for parallel checking the accuracy of the measurements. The proton beam energies is E_{lab}~200÷1000 keV and beam current I_p is up to 60 mA at high energy stability. The machine provides heavy ion acceleration also. The experimental set up includes a scattering chamber and the independent beams intersect in the chamber's centre. Protection from carbon build up and target cooling are provided for. Ge-detectors provide for measurements of the angular distributions of γ-quanta within 0°÷170°. Semiconductor detectors for detection of the charged reaction products are available.

Argonne tandem linear accelerator system "ATLAS" (ANL, Argonne, USA) facility.

The superconducting ATLAS accelerator has two ion sources based on an electron cyclotron resonance source and a tandem accelerator for the beam injection. It accelerates a wide spectrum of ions (practically any stable nucleus) up to the energy of ~ 10 MeV per nucleon. A "converter" (a liquid nitrogen cooled deuterium sell) for radioactive ion beam generation as well as some precise detection set-ups are available.

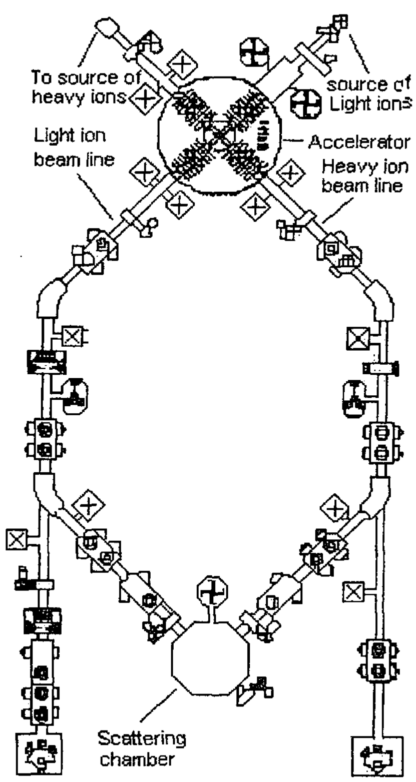

Fig. 4. UKP-II-1 facility.

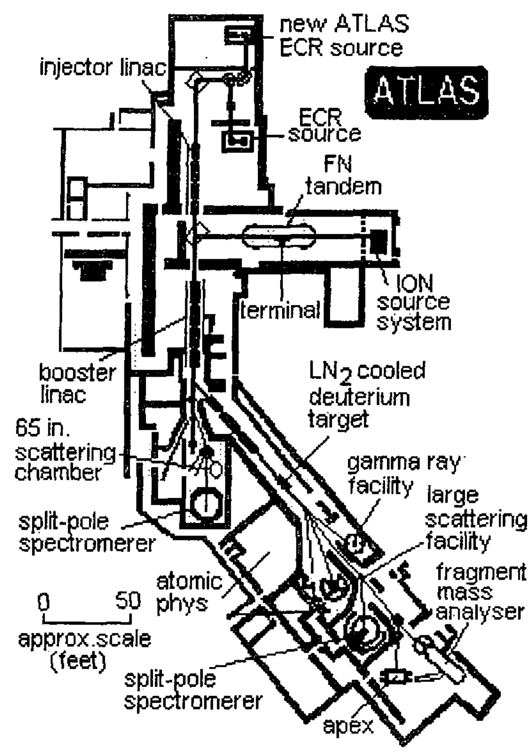

Fig. 5. Scheme of the ATLAS facility.

IV. ACTIVITY OF THE INSTITUTIONS IN THE NUCLEAR ASTROPHYSICS AREA

A number of interesting results were obtained by the INP AS of Uzbekistan and the INP NNC of Kazakhstan. A large part of these investigations is correlated in the framework of the Agreement on scientific-technical cooperation between these Institutions.

Below we enumerate some results of astrophysical reactions, which have been obtained by the experimentalists and theorists within these collaborations. The theoretical approaches and experimental techniques of the institutions have been used.

1. The $^{12}C(p,\gamma)^{13}N$ proton capture reaction is the input reaction of the dominant CNO-cycle chain:

$$^{12}C(p,\gamma)^{13}N(e^{+}\nu)^{13}C(p,\gamma)^{14}N(p,\gamma)^{15}O(e^{+}\nu)^{15}N(p,\alpha)^{12}C$$

Experimental data exist within the range of 72÷541 keV. The discrepancy in the available experimental data at the minimal energies is large (>40%). Differential cross sections of the $^{12}C(p,\gamma)^{13}N$ reaction have been directly measured by the group of Prof. N Burtebaev (INP NNC, Almaty) within the energy region E_p = 350 ÷ 1100 keV with experimental errors ≤10% using the UKP - 2 accelerator.

The excitation function of the $^{12}C(p,\gamma)^{13}N$ reaction is presented in figure 6. The errors are less the sizes of experimental points. For the data of Rolfs: see ref. [17]. The isotropy of the angular distribution was confirmed.

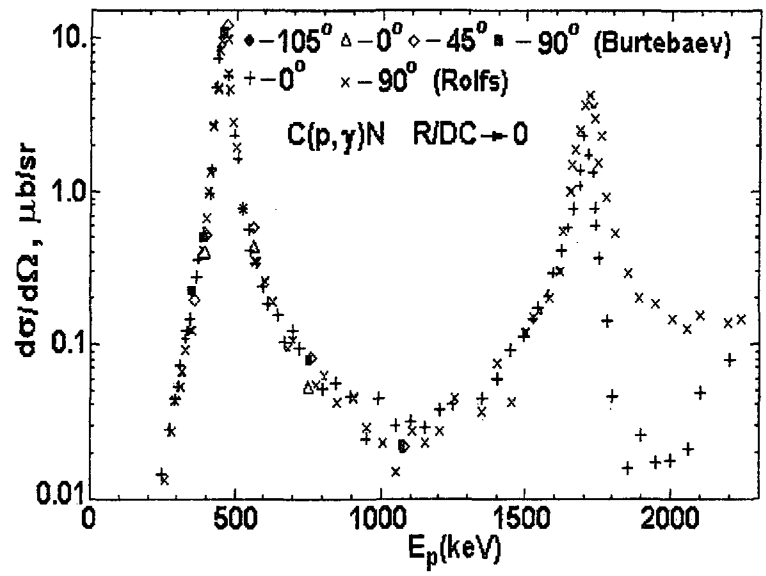

Fig. 6. Excitation function of the $^{12}C(p,\gamma)^{13}N$ reaction

The calculation of the astrophysical S–factor for the $^{12}C(p,\gamma)^{13}N$ reaction was fulfilled by R. Yarmukhamedov at the INP AS RUz. The nuclear vertex constant [14,21] was used for the virtual decay $^{13}N \rightarrow ^{12}C+p$ ($G^2 = 0.34$ fm) to fix the direct capture part within the R–matrix approach. The resonance parameters from data referred in [22] were used:

Γ^{γ}=0.67eV, Γ^{p}=31.7 keV for 2.37 MeV; $J^{\pi}=1/2^{+}$ level,
Γ^{γ}=0.64eV, Γ^{p}=62 keV for 3.51 MeV; $J^{\pi}=3/2^{-}$ level.

A good agreement with the experimental astrophysical S – factor at extremely low energies was achieved.

2. The $^{16}O(p,\gamma)^{17}F$ proton capture reaction.

The measurements of differential cross sections of the reaction $^{16}O(p,\gamma)^{17}F$ at 0^0, 45^0, 90^0 and 135^0 and excitation functions within the range 550 ÷ 1100 keV were carried out on the UKP-2-1 installation by Prof. N. Burtebaev and his group. Data on elastic scattering $^{16}O(p,p)^{16}O$ were obtained too. The excitation function for the $^{16}O(p,\gamma)^{17}F$ reaction at 90^0 is shown in figure 7.

The astrophysical S-factor, penetrability of the potential barrier and reactions rates have been calculated. Good agreement for calculated cross section of the $^{16}O(p,\gamma)^{17}F$ reaction with experimental values and results of the other theoretical works is achieved.

3. The $T(\alpha,\gamma)^7Li$ reaction. The experimental astrophysical S-factor measured at rather low energies can be used as an independent source for getting the ANCs (inverse task). In this case energy points should be used where the resonant contribution is negligible. The obtained ANCs are used for the calculation S-factor at extremely low energies (including zero value) where experimental values cannot be obtained.

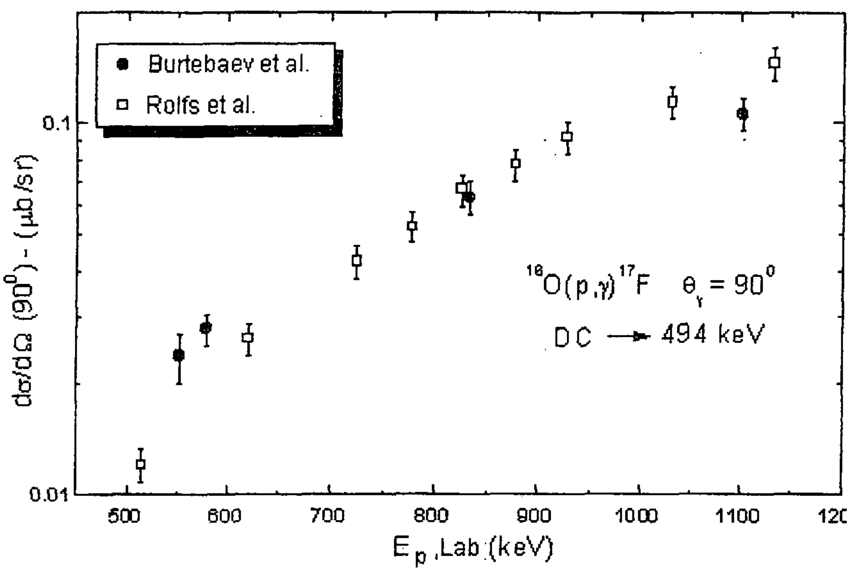

Fig. 7. Excitation function of the $^{16}O(p,\gamma)^{17}F$ proton capture reaction. Data of Rolfs – see [23].

This method, developed by R.Yarmukhamedov and S. Igamov, allows one to exclude the model dependence of the calculated direct astrophysical S-factor on the geometric parameters of the Woods-Saxon potential, and on the parameters of the optical model. The method has been applied for the $T(\alpha,\gamma)^7Li$ reaction (see figure 8). A more accurate value of $S(0)=\{0.097\pm0.010\}$ keV·b is obtained.

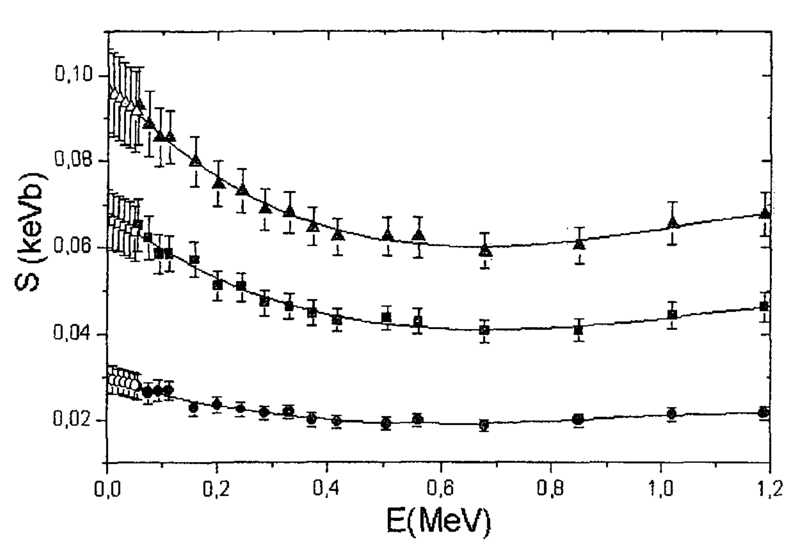

Fig. 8. Astrophysical *S* factors for $T(\alpha,\gamma)^7Li$. The lower curve is the S-factor for population of the first excited state (0.478 MeV), middle - for G.S.), and upper – the total. Filled points are experimental data of C.R. Brune et al., Phys. Rev. 1994 and the open points are the calculated extrapolation. The solid lines are the curves of the polynomial fits to the experimental and calculated data.

4. ANCs obtained from (^{3}He,*d*) reactions.

A set of experiments for obtaining ANCs have been carried out with beams from the INP RUzb U-150, INP NNC RKaz and Moscow State University INP cyclotrons using (^{3}He,*d*) reactions by the group of INP RUzb [14,15]. The values of ANCs obtained from the analysis of these and available data in the literature were averaged over the used projectile energies and for the various acceptable model parameters. The results are listed in the table 1.

Table 1.

E^*, MeV (J^π)	nlj	C^2, fm^{-1}
$^{10}B \to {}^{9}Be+p$	ε_p=6.587 MэB	
0.0 (3^+)	$1p_{3/2}$	5.26±0.37
0.718 (1^+)	$1p_{1/2}$	5.50±0.41
	$1p_{3/2}$	2.98±0.30
1.74 (0^+)	$1p_{3/2}$	8.0±0.6
2.16 (1^+)	$1p_{3/2}$	1.46±0.17
3.59 (2^+)	$1p_{1/2}$	0.26±0.06
4.77 (3^+)	$1p_{3/2}$	0.029±0.006
5.11 (2^+)	$2s_{1/2}$	0.099±0.017
5.17 (2^+)	$1p_{1/2}$	0.33±0.10
5.92 (2^+)	$1p$	~ 0.3
6.03 (4^+)	$1f_{7/2}$	~ 4×10^{-3}
6.13 (3^-)	$1d_{5/2}$	~ 0.23
6.57 (2^+)	$1p_{3/2}$	~350
$^{11}B \to {}^{10}Be+p$	ε_p=11.23 MэB	
0.0 (0^+)	$1p_{1/2}$	27.5± 3.0
$^{11}C \to {}^{10}B+p$	ε_p=8.693 MэB	
0.0 ($3/2^-$)	$1p_{3/2}$	29± 5
2.00 ($1/2^-$)	$1p_{3/2}$	0.078 ±0.013
4.32 ($5/2^-$)	$1p$	1.8± 0.25
4.80 ($3/2^-$)	$1p_{3/2}$	0.107 ±0.010
$^{12}C \to {}^{11}B+p$	ε_p=15.96 MэB	
0.0 (0^+)	$1p_{3/2}$	223±31
4.439 (2^+)	$1p_{1/2}$	15.8 ± 3.5
7.654 (0^+)	$1p_{3/2}$	1.27 ± 0.42
9.641 (3^-)	$1d_{5/2}$	0.58 ± 0.11
12.71 (1^+)	$1p_{1/2}$	1.88 ± 0.24
15.11 (1^+)	$1p_{1/2}$	~0.07
$^{13}N \to {}^{12}C+p$	ε_p=1.943 MэB	
0.0 ($1/2^-$)	$1p_{1/2}$	3.26±0.25

E^*, MeV (J^π)	nlj	C^2, fm^{-1}
$^{14}N \to {}^{13}C+p$	ε_p=7.549 MэB	
0.0 (1^+)	$1p_{1/2}$	18.8 ± 1.7
	$1p_{3/2}$	~0.74
2.313 (0^+)	$1p_{1/2}$	13.0 ± 2.4
3.948 (1^+)	$1p_{1/2}$	2.54 ± 0.43
4.915 (0^-)	$2s_{1/2}$	14.1 ± 3.9
5.106 (2^-)	$1d_{5/2}$	0.42 ± 0.06
5.690 (1^-)	$2s_{1/2}$	9.3 ± 3.1
5.83 (3^-)	$1d_{5/2}$	0.18 ± 0.04
6.204 (1^+)	$1p_{1/2}$	~0.06
6.444 (3^+)	$1f_{7/2}$	(22±7)×10^{-5}
7.028 (2^+)	$1p_{3/2}$	0.22±0.06
$^{15}O \to {}^{14}N+p$	ε_p=7.291 MэB	
0.0 ($1/2^-$)	$1p$	61 ± 9
5.183 ($1/2^+$)	$2s_{1/2}$	0.10 ± 0.03
5.241 ($5/2^+$)	$1d_{5/2}$	0.12± 0.03
6.176 ($3/2^-$)	$1p_{1/2}$	0.42± 0.08
6.793 ($3/2^+$)	$2s_{1/2}$	18 ± 4
$^{17}F \to {}^{16}O+p$	ε_p=0.598 MэB	
0.0 ($5/2^+$)	$1d_{5/2}$	0.89± 0.10
0.495 ($1/2^+$)	$2s_{1/2}$	5355± 670
$^{20}Ne \to {}^{19}F+p$	ε_p=12.84 MэB	
0.0 (0^+)	$2s_{1/2}$	245± 30
1.634 (2^+)	$1d$	36± 8
	$1d_{5/2}$	26± 6
	$1d_{3/2}$	10± 3
$^{27}Al \to {}^{26}Mg+p$	ε_p=8.272 MэB	
0.0 ($5/2^+$)	$1d_{5/2}$	37± 5
0.844 ($1/2^+$)	$2s_{1/2}$	420± 37
2.981 ($3/2^+$)	$1d_{3/2}$	21± 2.5

It is preferable to revise these data. For obtaining these data the optical model parameters were used without restriction on any criteria. In the analysis of most of the reactions effects of the channel coupling were not taken into account. So some inconsistency exists for the collected data.

5. $^{15}O(\alpha,\gamma)^{19}Ne$ and $^{18}Ne(\alpha,p)^{21}Na$ reaction studies in inverse kinematics. These are the routes for breakout from the hot CNO cycle into the *rp* process in accreting neutron stars:

$$^{15}\mathbf{O}(\alpha,\gamma)^{19}\mathbf{Ne}\rightarrow$$

$$^{12}\mathbf{C}(p,\gamma)^{13}N(p,\gamma)^{14}O(e^+\nu)^{14}N(p,\gamma)^{15}O(e^+\nu)^{15}N(p,\alpha)^{12}\mathbf{C}$$

$$^{14}O(\alpha,p)^{17}F(p,\gamma)^{18}Ne(e^+\nu)^{18}F(p,\alpha)^{15}O(e^+\nu)^{15}N(p,\alpha)^{12}\mathbf{C}$$

$$^{18}\mathbf{Ne}(\alpha,p)^{21}\mathbf{Na}\rightarrow \text{NeNa hot cycle}$$

The astrophysical rates of the reaction $^{15}O(\alpha,\gamma)^{19}Ne$ depends critically on the decay properties of excited states in ^{19}Ne lying just above the $^{15}O+\alpha$ threshold. In [24] the $p(^{21}Ne,t)$ and $^{3}He(^{20}Ne,\alpha)^{19}Ne^{*}$ reactions in the inverse kinematics were studied for obtaining of the radiative widths of these states. A high-precision measurement of excitation energies in ^{22}Mg was performed using the $^{25}Mg(^{3}He,^{6}He)^{22}Mg$ reaction to study his proton-rich, astrophysically interesting nucleus [25] using the Enge split-pole spectrograph at Yale. The excitation function for the inverse $^{21}Na(p,\alpha)^{18}Ne$ reaction was measured [26] using in-flight facility of the ATLAS accelerator (ANL). The ^{21}Na beam was produced via the $d(^{20}Ne,^{21}Na)n$ reaction. Excited states populated in ^{21}Na were studied through a measurement of the $^{21}Na(p,p')^{21}Na$ with the same set-up. To obtain the astrophysical $^{18}Ne(\alpha,p)^{21}Na$ reaction rate, the principle of detailed balance was used.

V. POSSIBLE DIRECTIONS OF JOINT INVESTIGTIONS

Here we discuss the actual tasks of nuclear astrophysics guided by the ANC method which can be solved by a united efforts within the framework of a ANL (USA)-INP AS RUzb-INP NNC RKaz collaboration. It would be done by obtaining the ANCs with the highest accuracy as possible using:

- three-particle Coulomb dynamics within DWBA should be correctly taken into account;
- role of coupled-channel effects should be analyzed;
- "non peripheral" part of the reaction amplitude should be evaluated.
- more precise definition of the parameters of bound state (Woods-Saxon) potential as well as the optical parameters should be done.

At the experimental aspect it is necessary to:

- choose the most preferable "projectile-outgoing" pairs in the nucleon and alpha transfer reactions;
- increase the precision of the data measurement in the transfer and radiative capture reactions.

As stressed above, loosely bound nuclei are preferable to use as a reaction participants. It is expedient to use the $A(^{3}He,d)B$ for obtaining ANC on the INP AS RUzb – INP NNC RKaz cyclotron facilities. The proton separation energy $\varepsilon_{3He\to d+p}$=5.49 MeV is relatively large but seems to be admissible. The analogous reaction $A(t,d)B$ ($\varepsilon_{3H\to d+n}$=6.26 MeV) for the ANC $B\to A+n$ requires a radioactive triton beam (or radioactive target ^{3}H) which is more a complicated experimental problem. From this point of view using of the heavy ion beams (including radioactive beams) of the Argonne National Laboratory accelerator ATLAS is very promising. Two pairs of heavy ions (projectile and outgoing particles) are convenient for ANCs from *p*- and *n*- transfer reactions:

$A(^{13}N,^{12}C)B$ or **$A(^{17}F,^{16}O)B$** ($\varepsilon_{13N\to 12C+p}$=1.943 MeV; $\varepsilon_{17F\to 16O+p}$=0.6003 MeV) for ANC $B\to A+p$;
$A(^{13}C,^{12}C)B$ or **$A(^{17}O,^{16}O)B$** ($\varepsilon_{13C\to 12C+n}$=4.946 MeV; $\varepsilon_{17O\to 16O+n}$=4.143 MeV) for ANC $B\to A+n$.

The separation energies are significantly less at these cases, and corresponding ANCs are rather well known [14,18]. Additionally, the first excited states of outgoing ^{12}C or ^{16}O particles lie rather high (4.44 and 6.05 MeV respectively), so their interference with low lying states of the final nuclei B is inhibited. The reactions with cluster nuclei $^{6,7}Li$ and radioactive ^{7}Be can be used for $B\to A+\alpha$ ANCs ($\varepsilon_{6Li\to\alpha+d}$=1.474 MeV, $\varepsilon_{7Li\to\alpha+t}$=2.467 MeV and $\varepsilon_{7Be\to\alpha+3He}$=1.5866 MeV).

As an example the reactions are listed in Table 2, which would be used for obtaining ANCs $\{B\to A+(p,\ n \text{ or } \alpha)\}$ Mostly stable (or long living nuclei) are included as a target, and all considered nuclei have relatively small of transferred nucleon separation energies ($\varepsilon_{B\to A+N} \le 8$ MeV).

Table 2.

$B \to A+p$	Reaction	$\varepsilon_{B\to A+p}$, MeV	$B \to A+n$	Reaction	$\varepsilon_{B\to A+n}$, MeV
$^{3}He \to d+p$	$^{2}D(^{13}N,^{12}C)^{3}He$	5.49	$^{10}Be \to ^{9}Be+n$	$^{9}Be(^{13}C,^{12}C)^{10}Be$	6.81
$^{7}Be \to ^{6}Li+p$ *)	$^{6}Li(^{13}N,^{12}C)^{7}Be$	5.61	$^{12}B \to ^{11}B+n$	$^{11}B(^{13}C,^{12}C)^{12}B$	3.37
$^{10}B \to ^{9}Be+p$	$^{9}Be(^{13}N,^{12}C)^{10}B$	6.51	$^{16}N \to ^{15}N+n$	$^{15}N(^{13}C,^{12}C)^{16}N$	2.49
$^{14}N \to ^{13}C+p$	$^{13}C(^{13}N,^{12}C)^{14}N$	7.55	$^{17}O \to ^{16}O+n$	$^{16}O(^{13}C,^{12}C)^{17}O$	4.14
$^{17}F \to ^{16}O+p$	$^{16}O(^{13}N,^{12}C)^{17}F$	0.601	$^{18}O \to ^{17}O+n$	$^{18}O(^{13}C,^{12}C)^{19}O$	3.96
$^{18}F \to ^{17}O+p$	$^{17}O(^{13}N,^{12}C)^{18}F$	5.61	$^{20}F \to ^{19}F+n$	$^{19}F(^{13}C,^{12}C)^{20}F$	6.60
$^{21}Na \to ^{20}Ne+p$	$^{20}Ne(^{13}N,^{12}C)^{21}Na$	2.43	$^{27}Mg \to ^{26}Mg+n$	$^{26}Mg(^{13}C,^{12}C)^{27}Mg$	6.44
$^{22}Na \to ^{21}Ne+p$	$^{21}Ne(^{13}N,^{12}C)^{22}Na$	6.74	$B \to A+\alpha$		
$^{25}Al \to ^{24}Mg+p$	$^{24}Mg(^{13}N,^{12}C)^{25}Al$	2.29	$^{6}Li \to d+\alpha$	$^{2}D(^{6}Li,d)^{6}Li$	1.474
$^{26}Al \to ^{25}Mg+p$	$^{25}Mg(^{13}N,^{12}C)^{26}Al$	6.31	$^{10}B \to ^{6}Li+\alpha$	$^{6}Li(^{6}Li,d)^{10}B$	4.462
$^{29}P \to ^{28}Si+p$	$^{28}Si(^{13}N,^{12}C)^{29}P$	2.75	$^{18}F \to ^{14}N+\alpha$	$^{14}N(^{6}Li,d)^{18}F$	4.42
$^{12}N+p \to ^{13}O$	$^{14}N(^{12}N,^{13}O)^{13}C$	1.514	$^{19}F \to ^{15}N+\alpha$	$^{15}N(^{6}Li,d)^{19}F$	4.013
$^{14}O \to ^{13}N+p$	$^{14}N(^{13}N,^{14}O)^{13}C$	4.63	$^{20}Ne \to ^{16}O+\alpha$	$^{16}O(^{6}Li,d)^{20}Ne$	4.73
$^{18}Ne \to ^{17}F+p$	$^{14}N(^{17}F,^{18}Ne)^{13}C$	3.52	$^{18}Ne \to ^{14}O+\alpha$	$^{6}Li(^{14}O,^{18}Ne)^{2}D$	5.11
$^{21}Na \to ^{20}Ne+p$	$^{3}He(^{20}Ne,^{21}Na)^{2}D$	2.43	$^{19}Ne \to ^{15}O+\alpha$	$^{6}Li(^{15}O,^{19}Ne)^{2}D$	3.54

SUMMARY

It is of great interest to carry out a study of peripheral one-particle transfer reactions at energies of ~10 MeV/nucleon for obtaining data for the calculation of S-factors and rates of radiative capture reactions at the astrophysical relevant energies.

For this goal the joint use of existing facilities of the Institute of Nuclear Physics (Tashkent, Uzbekistan), Argonne National Laboratory (Argonne, USA) and of the Institute of Nuclear Physics of the National Nuclear Center of Kazakhstan (Almaty) as well as the development of the relevant theoretical approaches would be highly encouraged.

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ON-SITE AND OFF-SITE FORENSIC ANALYSIS CAPABILITIES FOR PROLIFERATION AND TERRORISM PREVENTION

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INTRODUCTION

With the clandestine proliferation of improvised weapons of mass destruction (WMD) becoming a concern for global security and the need to adequately monitor our countries border to help prevent WMD terrorist attacks, requires special technologies. The more information that is available to identify WMD materials in the field can potentially provide law enforcement and first responders with the necessary information to prevent these situations from occurring. This task is becoming more demanding and complicated as we put more demands on our on-site chemical screening and detecting systems to prevent attacks and protect the nation's borders. The Forensic Science Center (FSC) at Lawrence Livermore National Laboratory (LLNL), with the assistance of other DOE labs such as Savannah River National Lab and Sandia National laboratories are providing the Department of Homeland Security (DHS) with such detection technologies. Examples of the technical capabilities developed at LLNL's Forensic Science Center are on-site and off-site chemical analyses include:

1. Having a deployment team in readiness to support DHS responders
2. Development of analysis techniques and protocols for field screening.
3. A coordinated network of LLNL analytical labs ready for response to WMD samples
4. A certified ISO-17025 quality control program to assure law enforcement sample handling requirements.

Even with state-of-the-art monitoring and interrogative systems, coordinated and comprehensive forensic analysis and response will be critical in both pre and post event involving WMD events. Several LLNL developed on-site detection technologies have been utilized to address some of these on-site screening and analysis needs:

- Portable thin layer chromatography kit (TLC)
- Colorimetric spot tests
- Portable gas chromatography-mass spectrometer (GC-MS)

Each on of these technologies is described in some detail highlighting its usefulness in an emergency deployment or field-monitoring situation.