REVIEW OF THE ISTC INNOVATIVE NUCLEAR PROGRAMS
(INFORMATION REVIEW)

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Introduction

The ISTC is a unique international organisation created more than ten years ago by Russia, USA, EU and Japan in Moscow. The basic idea behind establishing the ISTC was to support non-proliferation of the mass destruction weapons technologies by re-directing former Soviet weapons scientists to peaceful research thus preventing the drain of dangerous knowledge and expertise from Russia and other CIS countries.
Numerous science and technology projects are realised with the ISTC support in different areas, from biotechnologies and environmental problems to all aspects of nuclear studies, including those focused on the development of effective innovative concepts and technologies in the nuclear field, in general, and for improvement of nuclear safety, in particular. The presentation addresses some technical results of the ISTC projects as well as methods and approaches employed by the ISTC to foster close international collaboration and manage projects towards fruitful results.

To better contribute to the solution of national and international science and technology problems, and to match Russia and CIS scientific potential and expertise to the needs of the world science, industries and businesses, since 1997 the ISTC has been pursuing its Partner program.
The Partner Program provides opportunities for private industry, scientific institutions, and other governmental or non-governmental organizations to fund research at CIS institutions via the ISTC.

Presently, the ISTC now has 37 member countries (25 from EU), representing the CIS, Europe, Asia, and North America. The Partner list includes over 180 organizations and leading industrial companies from all ISTC parties.

ISTC Activities to May 2006: about 2350 projects approved for funding.
Above $700 million in funding committed.
More than 350 institutions and 35,000 specialists receive grants from ISTC.

Among five thousand project proposals submitted to ISTC, there are about five hundred related to different aspects of nuclear technologies and Nuclear Fuel Cycle (NFC).

These aspects are:

- General technical and economical analysis of NFC, including non-proliferation issues.
- New and advanced nuclear fuels and fuel elements.
- Reprocessing of spent fuel, including transmutation of minor actinides and fission products.
- Plutonium disposition – safety, economics, technology.
- Fuel transport and storage.
- RAW management and burial.
- Nuclear data, data bases and computer modelling.
- Experiments: critical, non-reactor, benchmarks.
- NFC simulators and training centers.
- Nuclear power in space, and others.
- Radiation conditions in the NPP.
- Sky-shine experiments.

Challenge of the World Nuclear Community is to prove to Public over the World, that newly proposed nuclear concepts are safe and effective.
The only acceptable method, which is trusted and accepted by Public both now and always, is basic and demonstration-type Experiment, in advance of computer or paper-type arguing.
Important, that results of these experiments are to be available for international analysis.

Problems are that nuclear experiments are very complex, its require special licensing, long time preparation, high-skilled personnel, purchasing by special materials and tools, raised budgeting.

In this sense the ISTC clients (first of all – nuclear and "nuclear weapon" institutes in Russia and CIS) have all set, ready, licensed, and equipped unique nuclear installations, high-skilled personnel, good cooperation.
Essential, that the ISTC projects:
•• are managing internationally;
•• have plans and results, available for international collaborators;
•• results may be passed to international centers (OECD/NEA and/or others) for further international benchmarking.

As for today - a set of demonstration and basic-type experiments, which fit closely with INPRO and GIF program, with EU Frame-Work programs, - had been done or under development now in the frame of ISTC projects and programs with active international collaboration. The ISTC - as an unique international tool – is ready to take part and manage further this activity.

The following information will be included in the review, with special attention on details of corresponding corresponding experimental programs:

- Novel reactor concepts, fit with GIF and INPRO:
  - Supercritical Pressure Water aspects.
  - Heavy metals (Lead, Lead-Bismuth) technology.
  - HTGR – critical modeling, engineering.
  - Molten salts.
- Reactor data benchmarking.
- Accelerator Driven Systems (experimental modelling).
- Nuclear data measurements.
- Severe accident study (corium modelling, QUENCH, Chernobyl).
- Experimental Analysis of Hydraulically Induced Vibrations in Compact Curling Tube Steam Generators.

Novel reactor concepts, fit with GIF and INPRO

NPP with Supercritical Pressure Water (new proposals)

- **Aspects of application of Supercritical Pressure Water (# 2689 - IPPE, Obninsk).**

An overview of available information will be carried out on the problems of SCP power plants including physical and thermal hydraulic processes, water regimes under different operating conditions, solubility of structural materials, peculiarities of equipment operation under high temperature and pressure conditions, mechanical properties of structural materials. On this background, physical, thermal and strength evaluations and safety assessments will be made.

The control experimental investigations, based on the thermal simulation methodology, will be carried out on a special Thermal test facility. Using of modeling fluid with low critical parameters (pressure, temperature, and heat capacity or heat evaporation) permits simplify and reduce cost of the experiments.

- **Computer modeling for Channel-Type Reactor with Coolant of Supercritical Parameters (# 3213 – NIKIET, Moscow).**

The Project objective is to create a package of computer models and codes for design features and specific characteristics of channel-type reactor cooled by light water of supercritical parameters and moderated by heavy water.
The codes will allow to study stationary and transient 3D neutronic and thermohydraulic processes.

Heavy-metal technology (Lead, Lead-Bismuth)

- **Critical experiments**

These experiments, carried out on BFS critical assembly, are focused on confirmation of predictable neutron-physical characteristics of reactor core with heavy coolant. The benchmark-model of the experiments will be created for its verification and validation, for estimation of uncertainties connected with both distinction of the model from the real experiment and of material composition, geometry, etc., and for further corrections.

- **Basic of HM technology**

This set of the projects includes both experimental study and summarising of relevant data , for instance: Hydrodynamics and heat/mass transfer processes in liquid metals (reference manual #1611), Heavy liquid metals interaction with structural materials, water, air (#1652), Improvement of corrosion resistance of constructional steels in liquid Pb and Pb-Bi alloys (#2048), Laser separation of Lead isotopes (#2573), Control of Oxygen content in Lead coolants (#3020).

HTGR

- **Critical experiments**

Critical experiments at the modified ASTRA critical facility, RRC Kurchatov Institute, will be created for validation safety and inherent self-protection of HTGR-M with uranium fuel, including measurement of temperature reactivity effects and its constituents for core heated from 20°C up to 600-850°C, and control rods worth of as a function of temperature (#0685.2).

- **Components of gas (helium) technology**

Experimental study of technologies for high-temperature components, recuperator, creation of the stand for turbo-compressor materials testing, development of uranium and U-Pu microsphere-type fuel (#352, #769, #1313, #1410).
Experimental study of the cooler model, Creation of gas seal for shaft and Experimental study of the seal mock-up, Design of powerful diaphragm coupling (#2379, #2395, #2399, #2400).

- **Gas-cooled fast breeder reactor**

Design of 1000 MWe power facility with a fast helium-cooled reactor BGR-1000 is based on the concept of the core fuelled by coated microfuel and directly cooled by the cross flow of the helium coolant of moderate temperature.
Basic requirements to a reactor design include such as:

- thermal efficiency is not lower than 48-55%;
- exclusion of essential radiation consequences of any any severe accident or diversions due to the application of multilayer protective coatings and preserving integrity at temperatures up to 1600°C;
- nonpositive void and other reactivity effects (#2973, RRC Kurchatov, Moscow).

Molten salts

- **MS (fluorides with actinides) – measurement of principal parameters**

The experimental stand Thermal Convection Loop was designed by the inter-institute team leaded by Kurchatov institute and VNIITF (Cheljabinsk-70) in the and assembled in the hot-chambers of VNIITF. Physical and chemical properties of new solvent systems with TRUs, PuF_3 additions and / or Th dissolved in molten 58NaF - 15LiF- 27BeF_2 (mole%) system are studied. Corrosion tests with load / no-load of Ni based materials at natural convection loop with molten salt (more than > 1500 hours, up to 100^{o}C, flow 5 cm/c) as well as and after-test examinations were done (#1606).

- **Curium in molten chlorides**

Thermodynamics of Curium in molten chlorides and formation of oxygen/ oxygen-free curium compounds are studied (#3261). These fundamental data can be subsequently used for feasibility assessment of the processes of curium recovery in molten chlorides. The application of the potentiometric titration method, using an oxygen pump made of zirconium-yttrium or zirconium-scandium ceramics, makes it possible to reduce by a factor of tens the amount of the studied element, which is involved in the experiment. This fact is of great importance because of a high curium cost.

- **Molten Salts for RAW Treatment**

Extraction and evaporation of a-LL nuclides, concentrating of the liquid RAWs, production of solid mineral-like matrix (#1608).

Reactor data benchmarking.

Set of the ISTC projects had been fulfilled in the frames of ISTC program “Plutonium disposition”. These benchmarks were focused on modeling of VVER-type reactors (## 371/ 371.2, #116, #1836) and modified fast reactors (#220, 650, 1483, 2423, 0731) with MOX and other plutonium fuel (particularly – weapon-grade Plutonium) and fit with the international program “Plutonium disposition in Russia”.

International collaboration (ORNL, INEEL, IRSN and others) is supporting the experimental program with unique in the World family of critical stands COBRA/ BFS in IPPE, Obninsk for ICSBEP benchmark Handbook of OECD/NEA. The program includes evaluation of critical safety uncertainty (#815), thorium critical experiments (#2432), fast reactor with lead coolant (#2661), justification of MA transmutation (#2884).

RAW transmutation

- **Nuclear data (in-reactor experiments)**

Radiochemical study and activation measurements of the isotopic composition changes of the minor actinide samples (U-234, Np-237, Pu-238, Pu-240, Am-241, Cm-243+Cm-244) irradiated in BN-350 reactor during several campaigns (#1372).

Based on the review of results of more than thirty related ISTC projects with respect to accuracy revealed in obtaining their main neutronics parameters, the project #2578 aims at definition and selection of vital parameters needed in further clarification through experimenting.
Thus, as a result, one could expect the priority list for future experimental and theoretical studies in the area of waste transmutation, proved by "supply-and-demand" evaluation and expert judgments.
The recommendation for transferring of measured data into proper data files and/or cross-section libraries will be made also.

- **Partitioning**

Projects #2068/ 3404: Systematic study of physical chemical properties of new calixarene extractants with functional groups of different types was done.
Target radionuclides were removed:
Pu > 99,999%; Am > 99,999%; Np > 99,0%;
U > 99,98%; Cm > 99,99%;
Nd, Pr, Ce, La and U were combined into REE strip product.
Am, Cm, Pu, Np, Eu, Sm, Y and Gd were combined into TPE strip product.
Authors can purify the Am – Cm fraction from heavy or from light REE in one extraction cycle.

Accelerator Driven Systems

- **Integral-type experiments with sub-critical blankets**

➢ **YALINA (14 MeV neutron generator with uranium blanket), #B-070.**

A sub-critical uranium-polyethylene assembly driven with a neutron generator of high intensity (10^{12} n/s for 14.1 MeV neutrons and $3 \cdot 10^{10}$ n/s for 2.5 MeV neutrons) and Cf-252 source was being put into operation in RPCP Institute in Minsk, Belarus. The neutron generator operates in two modes: continuous and pulse ones.

The methods of measurement of subcritical level, neutron source importance, reactivity effects in subcritical systems, spectral indexes, transmutation rates were elaborated and tested in the frame of the current project activity.
Measurements of neutron flux distributions over the uranium blanket with different configurations, neutron source importance, reactivity effects, subcritical levels, dynamic characteristics, spectral indexes, transmutation rates and etc. were performed at the sub-critical assembly (thermal spectrum) driven with the neutron generator. Transformation of blanket into fast booster-type zone with three experimental channels is planned. The YALINA program is accepted by international collaborators as the benchmark.

➢ **SAD (cyclotron with plutonium (MOX) blanket – project)**

The purpose of the project is to develop and create an experimental installation (SAD) on the basis of existing accelerator and a subcritical blanket with MOX uranium-plutonium fuel.
The experimental electronuclear installation will include:

- 660MeV proton accelerator;
- Beam transport channel;
- Heavy replaceable target (Pb, W, Pb-Bi);
- Sub-critical blanket with BN-600 type FE with $K_{eff} = 0.95$;
- Protective and supervision systems;
- Control and measuring complex.

The proton beam interacts with the target and produces neutrons, which enter the blanket. The uranium-plutonium blanket and the lead reflector surround the neutron source of the target. A small beryllium insert equipped with experimental channels will be placed behind the lead reflector.
The experimental program and technical project is managing by international SAD-YALINA Steering committee (projects #2267 and #B-070).

- **1 MW Pb-Bi target contour**

In the frames of #0559 project the pilot 1 MW molten lead-bismuth target complex TC-1 has been developed, fabricated and tested. Beam-off thermal hydraulics tests were made under isothermal conditions. Unique Russian experience with lead-bismuth alloy as coolant in nuclear submarines was implemented. Later the TC-1 has been actually delivered at the Harry Reid Center for Environmental Studies, University of Nevada Las Vegas (UNLV) - #2083. Now the set of joint experiments and tests are developing in UNLV.

Nuclear data measurements

- **Target (spallation)**

Different measurements of characteristics of spallation reactions cascade initiated by protons (with up to 3 GeV energy) in thin and thick targets were made in frames of more than dozen ISTC projects. Number and energy spectrum of neutrons, heat release, reaction products were measured for different target materials.

- **Blanket (MA, FPs).**

Transmutation efficiency of minor actinides (MA) and fission products (FP) were measured under neutron irradiation. Fast and thermal reactors and accelerators were used. About twenty fulfilled projects correspond to different neutron spectrum, exposure and other conditions. Review of the results of this program and recommendations was made specifically by #2578 project and evaluated by he CEG.

- **Structure materials study**

The purpose of the project #2048 is to develop and substantiate an effective way to protect constructive steels from corrosion in liquid Pb and Pb-Bi melts at temperatures higher than 500°C via modification of their surface properties with the help of pulsed intense electron beams. An increase in corrosion firmness is reached by formation of oxide covers or by surface doping of steels.

Severe accident study

About ten projects related to different aspects of severe nuclear accidents with degradation of core are being managed by international group of collaborators – CEG SAM. This group through its regular meetings (two times a year) and topical workshops coordinates projects with European FW programs and programs of other countries.

- **Corium study and modelling**

The ultimate goal of the proposed project is the nuclear reactor safety enhancement in case of a severe accident involving the core degradation.

The subject of project series #833 (METCORE), #1950 (CORPHAD), # K-1265 (INVECOR), # 3345 (EVAN) is in-depth theoretical and experimental study of physico-chemical processes taking place at core melt interaction with reactor vessel steel, for instance:
- corium melt (of different – vessel steel specimen interaction;
- degree of melt superheating;
- composition of above-melt atmosphere, inert and steam options are proposed for the Second phase;
- fission product release to the PWR containment atmosphere.

The results can be used for:
- elaboration of numeric models, codes and data for corium melt - vessel steel interaction processes;
- verification of calculation codes modeling free convection processes in the melt pool in terms of physicochemistry;
- calculation and safety upgrade of operated and designed reactors VVER, PWR and BWR.

- **Quench effect**

3194 (PARAMETER): Experimental investigation of behavior of fuel rod VVER-1000-type assemblies

under simulated conditions of a severe accident including the stage of low rate flooding from top or high rate flooding from top and bottom.
The experimental program include study of:
Thermal-mechanical and corrosion behavior of VVER fuel rod assemblies in simulated conditions of a severe accident development stages and determining their damage parameters.
Thermal-mechanical behavior of structural components of VVER fuel rod assemblies (fuel rod cladding, fuel pellets, guiding tube, spacing grids) under flooding from top/top and bottom of the lead assembly superheated up to 2000oC.
VVER fuel rod assemblies in condition of high rate flooding form top and simultaneous flooding from top and bottom.
Determining an oxidation degree of the VVER fuel rod assembly structural components.
Interaction and structural-phase changes in the VVER fuel rod assembly materials (fuel cladding, fuel pellets).
Hydrogen release rates under severe accident conditions including stage of bundle flooding.

1648/ 1648.2 (QUENCH): Development of data base to describe the VVER and PWR core behavior under severe accident conditions.
The primary task of the Project is to obtain data on VVER reactors core behavior under severe accident conditions in order to develop physical models and codes applicable to VVER reactors. This task is assumed to be solved as complementary to the QUENCH project in FZK, Karlsruhe. Realization of the same methodical approach will allow comparison of the behavior of VVER and PWR materials and design elements as well as to provide the possibility of application of the same approach to develop the numerical codes and determine safety criteria of these reactors.
Small-scale tests and an integral experiment under quench conditions are carrying out with VVER material in order to build up a database for modeling and verification of codes. The integral fuel bundle experiment will be carried out using non-irradiated materials. The small-scale experiments with irradiated fuel are assumed in order to develop basis for database for irradiated core materials.
The project includes three stages:
Study of the spent fuel rod segments (RIAR, Dimitrovgrad);
Integral experiment with model bundle with 31 fuel rod simulators under “quench” conditions (RIAR, FZK Karlsruhe);
FA Quench Model: Development of models and codes to describe VVER core behavior under “quench” stage conditions (RIAR, IBRAE, FZK).

#2936 (IBRAE): Modeling of reactor core molten materials behavior at consecutive stages of an accident development: from the early stage, when the core is mostly intact and the first Zr cladding melting occurs, to the late stage, when the core is completely degraded and a molten pool is formed in lower head of the PRV.
The following processes are studied:
Melt formation, onset of melt relocation:
Simultaneous dissolution of ZrO_2 crust and UO_2 fuel (fresh and irradiated) by molten Zircaloy,
Cladding oxide shell failure,
Release of U-Zr-O mixture from the cladding breach.
Candling process: flowing down in the form of drops and rivulets during the first stage of melt relocation;
Formation of massive coolant channel blockage (slug), its oxidation and downward relocation in the course of the second stage of melt relocation process;
Thermal hydraulic behavior of molten pool in the lower head of the RPV.

Chernobyl lava data-base

#2916 (CHESS): The "Chernobyl lessons" are very costly for the world society. That is why it is very important to understand them and make their most use. First and foremost, this concerns the results of the giant and practically unrepeatable "experiment" made on nuclear fuel of the Chernobyl’s reactor.

Understanding of the processes in this nuclear fuel during the active accident phase is of much importance for nuclear power safety-related issues. Such understanding is equally important for specific practical tasks to be solved in the future during removal of Fuel-Containing Materials (FCM) from the "Shelter".
The following main tasks to be solved under the Project may be subdivided into the following.
Task 1. Acquisition and analysis of the data on:
initial condition of nuclear fuel inside Unit 4;
post-explosion status of Unit 4; and
amounts and composition of released radioactive materials.
Task 2. Determining the key parameters (and their ranges) to be described by the future model based on analysis of verified data on:
composition and amount of radionuclides released from the core during the active accident phase;
nuclear, chemical and mineralogical composition of lave-like FCM;
geometry of intra-reactor compartments, etc.
Task 3. Collection of the data needed to determine concentrations of uranium and zirconium in metal corium generated during the accident for subsequent comparisons with the results of model calculations.
Task 4. Selection of the main FCM parameters and their simulation using the available calculated models.
Principal result: development of a model describing most accurately the processes of the active accident phase (corium behavior).
Task 5. Application of the results achieved in simulation of the selected FCM parameters for identification of both lacking input data and shortcomings of the available calculated models. Based on analysis and estimates of the results, development of proposals for the second phase of the Project and elaboration of approaches to solution of applied problems related to safety of the “Shelter”.
A distinctive feature of the Project consists in maximum possible use of huge and unique experimental data achieved during investigations at the "Shelter" - about 7000 measurements done during twenty years after accident.

Sky-Shine experiments
0517: Unique experiments had been done with especial experimental reactors located in desert area (Kazakhstan) for measuring of neutron and gamma scattering from clouds over more than 1 km radius. Dozen runs were done under different conditions. The results were transferred to OECD/NEA for international benchmarking.

Theoretical and Experimental Analysis of Hydraulically Induced Vibrations in Compact Curling Tube Steam Generators. (# 0502, Bauman TU, Moscow)
Goal of the project – to verify the ViCAN code via set of experiments and modeling at the family of three experimental stands:

- Bauman MGSU (TU), Moscow,
- Dollezhal NIKIET, Moscow,
- OKBM, N-Novgorod.

Resume
Goals of this presentation are to introduce some of the ISTC programs to international nuclear community to give examples of international cooperation, created in the frames of ISTC, to illustrate the statement of importance of international nuclear experiment as a tool for evidence of new nuclear concepts acceptance, and to make a call for further joint collaboration.

References

1.The ISTC Annual Reports - ISTC, Moscow, 1996 - 2005.
2 Web-site: www.istcinfo.ru