NUCLEAR PROPULSION – Conclusions from the Workshop on Nuclear Fission for Future Energy and Space Application: Thin Film and Other Unconventional Solution"

On the 10th and 11th May 2002, at the University of Rome "La Sapienza", a Workshop on Nuclear Propulsion was held. This Workshop was sponsored by ESF-European Science Foundation, with the title: "ESF-PESC Exploratory Workshop on Nuclear Fission for Future Energy and Space Application: Thin Film and Other Unconventional Solution".

The purpose was to review and discuss different propulsion systems based on advanced or innovative nuclear technology. Such propulsion is indispensable for interplanetary missions, as it has the potential for reducing overall mission cost and increased flexibility. The Workshop was attended by about 30 people from EU, USA and Israel, representing industries (Fiat Avio – Italy, AEA Technology – UK, Technicatome – France, etc.) and institutions (Carlo Rubbia – ENEA, ESA, NASA, St. Louis University, Ben Gurion University etc.). Collaboration between industry and academia was recognized key to future enterprise in this area. International collaboration was mentioned as essential and definitely wished, seeing the complexity, cost, safety considerations and standardisation of any nuclear reactor used for space propulsion. Much of the discussion during the second day of the Workshop was devoted to ways and means of jumpstarting initiatives in this field.

During the Workshop a spectrum of proposals and ideas were presented; they can grouped in three main areas.

1) *Direct conversion of fission heat into thrust*

The thin fissioning film solution ("Rubbia's engine") was presented and discussed by Carlo Rubbia (Nobel Prize in physics, 1984) himself. The role of Am^{242} was pointed out, and above all the fact that only Am^{242} may achieve criticality in a thin film state (0.2 microns is the thickness that was calculated, so that the fission product cannot trapped in the fuel). Prof. Y. Ronen-Ben Gurion University described a synthetic history of thin layer fission studies in Israel, leading to conclusions similar to those of C. Rubbia as to feasibility of using Am fission as energy source for interplanetary travel or even terrestrial power generation.. He showed results of calculations indicating ways Am^{242} may be obtained using a fast reactor: his results are very encouraging, and pave the way to substantial production of Am^{242}, i.e. far beyond what is needed to perform experiments. In the context of doing the experiments needed to validate his engine, C. Rubbia proposed the use of a cyclotron to simulate the behaviour of such scheme in a test facility. Ar ions created by spallation of protons would be the ersatz fission fragments family simulating actual fission products.

Nuclear Propulsion Projects developed in the past were presented by D. Froning – Flight Unlimited. In these systems the temperature and performance (differently from Rubbia's engine) is limited by the fact that the heat is transmitted through the reactor solid core (e.g., NERVA in US). Only Pebble Bed Reactors seemed to give higher performance due to the very nature of the topology of heating.

2) Nuclear Power used to produce directly electricity (so called NEP)

The concept system presented by Robert Bond (AEA Technology) exploits the heat from nuclear reactions to produce electricity in a thermodynamic cycle. The electricity is used in electromagnetic acceleration systems such as: MHD, RF heated plasma, ion propulsion, to produce thrust.

A. Ilin and A. Petro (NASA-JSC) presented the VASIMR MPD propulsion system. In the first pilot of this engine RF-heated plasma is expected to give a specific impulse 10 000 s with a thrust of 0,2 N. Questions on the plasma acceleration and radiative losses were raised by the audience.

Paul Czysz (St. Louis University) presented past experiments conducted at WPAFB to test high temperature gas and plasma acceleration by means of trains of RF pulses to heat the plasma. The main purpose at the time was to try replace conventional wind tunnels with MHD-accelerated wind tunnels.

3) Hybrid Systems

Methods that allow to increase the specific impulse obtained by nuclear thermal were discussed too. The use of low frequency (10 KHz) of RF inductive heating of H2 or other gas propellant was presented by C. Dujarric-ESA. Injection of liquid oxygen ("post combustion") could be possible in his concept, to increase thrust momentarily, as when attempting takeoff from the surface of a planet or satellite. Furthermore it was argued that the thermodynamic efficiency of the Power Generator would be increased by the temperature ratio between liquid hydrogen (before entering the nuclear heater) and the reactor temperature.

An important part at the Workshop were the free discussions had by participants both the first day, during scheduled talks, and the second day, explicitly dedicated to 'General Discussion and Roadmap Proposal'.

From these discussions some consensus emerged. Though nuclear technology for space mission presents some minuses, e.g., public acceptance, safety, application range, nevertheless it has some unique features that must considered . The use of nuclear propulsion allows wider mission ranges, enables shorter time, yields high power per given mass, in one word it gives much more **flexibility**. Dual use (e.g. power generation) gives a further reason to develop this technology.

J-P. Roux-Technicatome basing on experiences acquired in nuclear generators for submarines, proposed a roadmap, with a tentative kick off in 2003. The proposed work would start testing in orbit conventional NP, while studying 1 or 2 innovative and advanced NP concepts for a 2025 manned Mars mission.

FINAL PROGRAMME OF THE WORKSHOP

10th MAY

09.00-09.10 ESF introduction – Prof. Laurent
09.10-09.20 Welcome – Prof. Bruno
09.20-10.30 Rubbia
10.30-11.00 Ronen - Ben Gurion University
11,00-11,15 Discussion
11.15-11.30 Coffee Break
11.30-12.00 Bond - AEA Technology Space
12.00-12.30 Froning - Flight Unlimited
12.30-12.45 Discussion
12.45-13.45 Lunch Break
13.45-14.15 Dornbusch/Roux - Technicatome
14.15-14.45 Dujarric - ESA
14.45-15.00 Discussion
15.00-15.30 Czysz - St. Louis University
15.30-16.15 Ilin/Petro - NASA Johnson Space Center
16.15-17.15 Comments from ESA
17.15-18.15 Comments from Industries

11th MAY

9.00-12.00 General Discussion and Roadmap Proposals

FINAL LIST OF PARTICIPANTS

NAME	AFFILIATION	ADDRESS	TEL	FAX	E-mail
Atzei, Angelo	ESA	ESTEC Keplerlaan 1 P.O. Box 299 2200 AG Noordwijk The Netherlands	+31 (0)71 5653418	+31 (0)71 5655416	angelo.atzei@esa.int
Azzolari, Anna	CIGIEMME	Via Santuario, 18 20060 Ornago (MI) Italy	+39 0396010396	+39 0396010876	cigiemmeitaly@tin.it
Bond, Robert	AEA Technology Space	Culham Science Centre Abingdon Oxfordshire OX14 3ED UK	+44 (0) 1235 463402	+44 (0)1235 463285	robert.bond@aeat.co.uk
Cenci, Susanna	Alenia Spazio, Direzione Tecnologie Ricerca e Nuove Iniziative	Via Saccomuro, 24 00131 Rome Italy	+39 0641512503	+39 0641514432	s.cenci@rmmail.alespazio.it
Creta, Francesco	Università La Sapienza	Dip. Meccanica e Aeronautica V. Eudossiana, 18 00184 Roma Italy	+39 0644585786	+36 06483729	creta@pcprop5.ing.uniroma1.it
Czysz, Paul	St. Louis University	Aerospace Engineering Dept Cahokia, IL 62206 USA	+1 (618) 3377575	+1 (618) 3326802	p.czysz@worldnet.att.net
De Maria,Giovanni	Università La Sapienza	Dipartimento di Chimica V. Eudossiana, 18 00184 Roma Italy	+39 064462950	+39 0649913951	giovanni.demaria@uniroma1.it
Dornbusch, David	Technicatome	16, Rue Lentonnet 75009 Paris France	+33 1 44919426 +33 6 83364701	+33 1 42726551	david.dornbusch@technicatome.com
Dujarric, Christian	ESA	8-10 Rue Mario Nikis F-75738 Cedex 15 France	+33 (0) 153697514	+33 (0) 153697560	christian.dujarric@esa.int
Ferretti, Alberto	Fiat Avio	Corso Garibaldi, 22 00034 Colleferro (Rm) Italy	+39 0697285873	+39 0697285316	alberto.ferretti@fiatavio.it
Felici, Fabrizio	ESA	ESTEC Kepleran 1 P.O. Box 299 2200 AG Noordwijk ZH The Netherlands	+31 (0)71 5653436	+31 (0)71 5655421	fabrizio.felici@esa.int
Froning, H. David	Flight Unlimited	5450 Country Club Drive Flagstaff, AZ 86004-8739 USA	+1 (928) 5265916	+1 (928) 5265916	froning@flagstaff.az.us
Ilin, Andrew V.	NASA-JSC	Advanced Space Propulsion Laboratory NASA Johnson Space Center 13000 Space Center Blvd. Houston TX 77059 USA	+1 (281) 7925536 +1 (281) 7925675	+1 (281) 7925661	ilin@jsc.nasa.gov
Lang, Martin	ESA	ESTEC Kepleran 1 P.O. Box 299 2200 AG Noordwijk ZH The Netherlands	+31 71 5653817	+31 71 5655421	martin.lang@esa.int
Lorenzo, Martini	USA Embassy	Via Vittorio Veneto, 119/A 00187 Rome Italy	+39 06 46 74 24 35	+39 06 46 74 23 98	martinila2@state.gov

Mongelli, Sara	ASI	Via Villa Grazioli, 23 00198 Roma	+39 068567457	+39 068543871	sara.mongelli@est.asi.it
Negrotti, Alessandra	DRG Systems	Via S. Franca, 60 29100 Piacenza Italy	+39 0523334026	+39 0523334026	alessandra.negrotti@drgsystems.it
Nicolini, David	ESA	ESTEC Keplerlaan 1 P.O. Box 299 2200 AG Noordwijk The Netherlands	+31 (0) 71 5654973	+31 (0) 71 5655421	david.nicolini@esa.int
Petro, Andrew J.	NASA-JSC	Advanced Space Propulsion Lab. 2222222 NASA Johnson Space Center 13000 Space Center Blvd. Houston Texas 77059 USA		+1 (281) 7925661	andrew.j.petro1@jsc.nasa.gov
Ronen,Yigal	Ben Gurion University	Dept. Nuclear Engineering Ben Gurion University Beer Sheva 84105 Israel	+972 8 6461209	+972 8 6472889	yronen@bgumail.bgu.ac.il
Roux, Jean-Pierre	Technicatome	Commercial Direction BP 34000 Aix-en-Provence France	+33 4 42602214	+33 4 42602015	jean-pierre.roux@technicatome.com
Rubbia, Carlo	CERN	Building 864 2-D25 1211 Geneva 23 Switzerland	+41 22 76 72282		carlo.rubbia@cern.ch
Stalio, Roberto	ASI	Via Villa Grazioli, 23 00198 Roma	+39 06 85 67 285	+39 06 85 43 871	roberto.stalio@asi.it
Valorani, Mauro	Università La Sapienza	Dip. Meccanica e Aeronautica V. Eudossiana, 18 00184 Roma Italy	+39 0644585278	+36 06483729	valorani@dma.ing.uniroma1.it

Total number of participants: 24
13 from Italy, 5 from USA, 3 from France, 1 from UK, 1 from Germany, 1 from Israel
Age range: 29 – 70

Convenors:

BRUNO, Claudio	**Convenor**	University of Rome "La Sapienza", Dipartimento di Meccanica e Aeronautica Via Eudossiana 18 00184 Roma Italy	+39 06 44 58 52 80	+39 06 488 1759	c.bruno@dma.ing.uniroma1.it
DEL ROSSI, Alessio	**Co-Convenor**	University of Rome "La Sapienza", Dipartimento di Meccanica e Aeronautica Via Eudossiana 18 00184 Roma Italy	+39 06 44 58 52 72	+39 06 488 1759	alessio@pcmerlino.ing.uniroma1.it

ESF PESC representative:

LAURENT, Louis	Commissariat à l'Energie Atomique	CEA/Saclay, DSM/DRECAM Bâtiment 524 91191 Gif-sur-Yvette Cedex France	+33 1 69 08 69 14	+33 1 69 08 22 89	laurent@drecam.cea.fr