In the alternative, deformation of the burnout curve comes from variation of the original diameter of the fuel drops by the mixing system and not by the pressure and temperature on the rate of combustion. Suggesting in turn that while in the low-frequency range a 'consumption mechanism' prevails in the high-frequency, an instability dominates that is not related to variations in fuel consumption. This 'in-chamber' or Natanzon instability is reported to be experimentally confirmed.

Natanzon and the Russian phenomenological combustion model forms part of the bridge leading from analytical studies in the 1950s to the present computer simulations, where algorithms and codes are as important (some would claim more) for further progress as development of theory.

Many such theoretical assumptions or principles related to rockets became classified and as Fred E. C. Culick states in his preface this generated an 'asymmetry in the practice of open publication' (page xiv) so that scientists in the USSR knew much more. This book is a move towards more symmetry: even if it is a bit late in publication, it does highlight Natanzon's contribution for all to read.

Anders Hansson

Nuclear Space Power and Propulsion Systems. Progress in Astronautics and Aeronautics series Vol. 225

Edited by C. Bruno

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At the dawn of the public nuclear era in 1946, pioneers like L. Shepard understood that with this new power source the solar system would open up for human travel. In the same year the USSR refused the Baruch Plan that would have put all nuclear technology under United Nations control and with that decision the hope of fast development of space applications was gone.

That was not the same as no investments. The USA spent some \$3·5 billion (some \$10 billion today) from 1955 to 1971 under the Nuclear engine for the rocket vehicle applications (NERVA) programme. The result is impressive, some 23 different reactor/engines, one with peak power over 4,000MegaW that operated over one hour. The exhaust of the engine in the last days of the programme was calculated to have a specific impulse close to 850 seconds – that is almost three times that of the engines of Saturn V and twice the engines of the Space Transportation System/Shuttle. The cancellation of a human mission to Mars by 1972 terminated NERVA. Already the Partial Test-Ban Treaty in 1963, the outer space treaty from 1967 and internal politicking in NASA had ended the nuclear weapon powered concept, most often known as 'Orion'.

In the USSR a solid core engine was ready for flight testing around the 30 anniversary of Sputnik 1, the thrust was 3·57 tons, specific impulse up to 920 second, containing 7kg of uranium 235(90% enrichment) and it is claimed operated for one hour. This impressive engine was not the only nuclear development in the USSR and 38 reactors remain in orbit. Some has returned to Earth like the 'Mars-96' failure that returned with Plutonium and 'Cosmos-954' with Uranium.

In fact, prior to operation a fission reactor would produce a million times less radiation than that generated by the radioisotope thermal generators (RTG) on the 'Cassini' probe. The difficulties with RTG support (during President Clinton's time work on new such systems stopped) as well as public acceptance made larger nuclear use even more remote.

A decade after the collapse of the USSR had reignited the hope of international large scale nuclear development the International Academy of Astronautics accepted a proposal to review the state of nuclear propulsion and power. The starting point was again that 'nuclear energy was indispensable for space travel' (page 1) this time restating the hope of Esnault Pelterie in 1912. Even so RTGs or pulsed systems are not included, so the focus is firmly on reactor-based systems both thermal and electric. A review on ion-thrusters by the late David Fearn, another pioneer and one on high density electric propulsion from Germany add important aspects. The two appendices, the first on 'Radioactivity, Doses and Risks in Nuclear Propulsion' and the second on 'The Chernobyl Accident – A Detailed Account' illustrate the aim of the book to make nuclear applications in space as well as on Earth more acceptable.

Another more practical reason is provided: 'In terms of availability, prior expertise and know-how and overall performance, nuclear propulsion is a most attractive option for a broader class of interplanetary missions, including those with a human crew. It is because of this and other reasons that nuclear propulsion is among technologies given a higher priority by the European Union (EU) space industry.' (page 9).

Besides the fact that a nuclear stage was planned for the Europa III project between 1971-1973, the point is made that 'a nuclear thermal rocket's configuration is similar to that of a chemical system except that it requires a nuclear reactor as a heat source' (page 34). France supported a nuclear thermal program EOLE in 1993 and MAPS in 1995 with the long-term aim of sending humans to Mars, but it also considered a thermal nuclear stage on Ariane 5 operating also as a lunar tug delivering 7·5 tons.

Also the USA investigated nuclear thermal propulsion, some \$10 million of the \$430 million Project Prometheus programme – that had been supported during Sean O`Keefe`s time as NASA Administrator – being devoted to this research area. Even the small-scale Nuclear Electric Propulsion Space Test Program (NEPSTP) that aimed to link an USSR Topaz-2 reactor with UK and USA technology had its funding withdrawn. Hence the significant lack of practical experience: 'Although the US has carried out a number of space reactor programs since 1965, none of these subsequent programs led to a space-deployed reactor system and none completed the launch safety review process' (page 206).

To increase the possibilities of an end to this state 13 findings and recommendations are made by Roger X. Lenard (Chapter 6) based on commercial nuclear projects. All appear relevant and should be taken up.

However, since nuclear systems can provide not only power for propulsion and planetary habitats but even conceptually provide for the 'ability to rendezvous with star systems four to five light years distance within a human life span' (page 241) it would appear that more is needed than a reformed safety review process.

Without maturity via practical experience no technology can ever be selected and it is only via such selection for use that more public acceptance can be generated. The study group understand this and the first Appendix is aimed at explaining our radiation environment. Its final conclusion is significant: 'It is likely that no single event will assist the technical development of nuclear power and propulsion more than the reduction in costs and regulatory burdens generated by eliminating the linear no-threshold hypothesis as the basis for radiation health effects' (page 267). That hope will be difficult to fulfill for reasons not covered in the text but that should be known. In 2006 the National Academy of Sciences reviewed for the US government all papers that claimed to observe a threshold effect and concluded that the presented evidence was 'not sufficiently compelling'.

It is a lack of understanding of the mechanisms of cancer that is central to the no-threshold hypothesis that in turn predicts cancers resulting from very low levels of nuclear radiation. Further, the issue can not be resolved by statistics since even at levels of one million cases observed any effect is below the statistical uncertainty. Further, it is known that cancer deaths are lower in Denver, even if those living there are exposed to some 0·1 rem per year more than those living in New York City for example.

The risk that we all have of dying of cancer- at present around 30% – should not be used to stop a technology that can be made as safe as any technology that is at present accepted by the public. President Barack Obama cautiously called in February 2009 for 'a cure for cancer in our time' which could be used to challenge again the linear non-threshold idea from 1958 since it is – at least not yet – based on science.

Another important issue that is not covered in the book is proliferation. The fact that President Obama formed a non-proliferation office in the White House is just one indication. The fact that the UN proscribes the use of plutonium for space reactors is another. One possibility to overcome such issues would be the establishment of an international legal entity to develop and test space nuclear systems. It would have been helpful if such an idea had been examined in this study taking advantage of legal and other knowledge within the International Academy of Astronautics.

Several times the book hints that few in the public and even in the space community are aware of the different nuclear propulsion types and that both groups mix them up. At least partly this state is due to a lack of an integrated nuclear propulsion and power. At present it appears each topic has its own advocates when what is needed is a consensus depending on function like for a human crew (thermal?) or scientific instruments in flyby missions (nuclear electric?). After all the Russian argument that half the cost of any nuclear system is the cost of the safety demonstration is clearly correct.

One of the intended goals of the book was to provide a database on technical and safety and that has been achieved. The time from the Final Report (May 2006) and this book (July 2008) could have been used to take advantage of the fact that while the International Academy of Astronautics do not take positions, the convergence into a roadmap suggested above would have been very helpful to make the case for nuclear propulsion and power. Perhaps such activities could be the topic for a future volume.

Anders Hansson

Advanced Propulsion Systems and Technologies, Today to 2020. Progress in Astronautics and Aeronautics series Vol. 223

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In 1999 the European Space Agency (ESA) issued a request for proposals to take a look at the state of propulsion at that time and to 'try to predict which propulsion types would be the most promising and convenient in an overall sense' (page vii). With the short timescale of some 20 years the 'ultimate goal', it is stated, was to send signals for research investments.

The ESA programme Propulsion 2000 was completed in February 2003 and this book is the investigations of the winning team. The 'impact on the space market' contribution by Euroconsult of France 'proved to be optimistic' (page 1) but at the time of the 'Introduction' (dated 2007) the ever occurring 'encouraging signs' could be seen and 'space tourism' had made it in the long term market.

The first chapter provides the core method of ESA Propulsion 2000 with a 'feasible mission grid' and trade-off strategy. The conclusions are not surprising (page 17). In short they are:

- advanced solid motors… 'European industry can build solid motors competitive with those in USA, Russia, Ukraine or Japan'
- advanced cryogenic engines… 'In Europe, leadership and experience in this field are growing and should be maintained'
- electric propulsion… ' … it is mandatory to go from present experimental technology stage to ready-for-flight models'
- field effect electric propulsion (FEEP) systems … 'have been extensively studied in Europe where technology readiness level (TRL) is the highest'. So this type and micropropulsion, the last due to its links to biotechnology, is suggested for microsatellites.
- several nuclear fission systems are outlined all in need of political support.
- nuclear fusion as well as anti-matter and 'gravitational field propulsion' is labeled 'breakthrough' and regarded as of little interest to ESA.

In general: 'Common constraints for most of the propulsion systems described in the following chapters are low/zero toxicity, safety (on-ground and onboard), low cost compared to current systems and reliability' (page 17). While this comment is clear in relation to near term propulsions types, it is unclear how it can apply to high-energy lasers, mass accelerators and solar sails that are included. A final chapter 'In Situ Resource Utilisation' is also unclear with a timescale for human exploration being well outside 2020.

In fact in ESA the launcher following Ariane 5 is at present a fifth variant of 2016 and in 2025 a two-staged core-stage (2,500kN sea-level engine with liquid hydrogen and liquid oxygen) together with two solid boosters. The possibility of liquid boosters will be investigated .

In the USA the Delta IV RS-68 engine is developed into RS-68B for Ares V while Ares I appears far more politically sensitive. Space Exploration Technologies are working on 'Merlin' for Falcon 9 while hybrids are intended for Virgin Galactic suborbital system. So the near future is solids and liquids (hypergolic propellants will be reduced in use with liquid oxygen / kerosene likely to take over).

Chapter 2 is devoted to 'Advanced Solid Rocket Motors' the focus for Ariane 5 improvement and Ares I since 'compared to that by liquid rockets, solid propulsion is a more economical system for delivering very high thrust in a very short time' (page 20). The core is a listing of key technologies and technology readiness levels resulting in a roadmap. Sadly in this chapter, for most of the reproduced figures the darkness and small print make it very difficult to read. At least the roadmap should have got a full page and if needed those illustrations devoted to manufacturing reduced in number.

Chapter 3, 'Advanced Cryogenic Engines' is more theoretical than the one on solids but it does include components like magnetic bearings etc. One of its conclusions is that 'the greatest challenge in the development of oxidiser-rich technologies is material compatibility. There is extensive experience in this area in the United States and especially Russia; considering the present European technological readiness level, hot corrosion problems would make oxidiser-rich cycles very expensive to realise in the EU, both in terms of cost and time' (page 82). It is estimated in the roadmap that improved materials and designs of solid motors could 'reasonably lead to a 50% launch cost reduction in the short term' – before 2015 (page 84). Regarding reusables, the expectation is for a 'multistage configuration' but 'winged stages can, in the longer run, bring about a factor 10 in cost reduction' (page 84).

Liquid oxygen and hydrocarbon combinations has been used by most launchers developed in USSR/Russia and Chapter 5 covers

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