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.

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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 'the name, composition and a brief description of engines and their main units, structural and operational requirements put upon the engines, their problems, defects and ways of solving them are reported' (page 117). This Russian review is preceded by one on the situation in Europe focusing on (Fiat) Avio. While knowledge is mature in the US, it is Russia that remains leader, illustrated by the use of RD-180 on the Atlas upgrade.

Chapters 6 and 7 is devoted to what is called 'Green Propellants' the first outlining a €1·5 million a year ESA program and the second from Russia. The latter is more fundamental but regards most propellants as 'green' due to their mainly local environmental effects with liquid oxygen 'perhaps the most ecologically friendly' and liquid hydrogen a 'close second'.

An alternative future to ever increased payload mass and no significant increase in the number of launchers is discussed in Chapter 8 on 'Miniaturised Propulsion'. In this future, functionality is divided between several satellites that integrated provide the function of our present satellites. Smaller platforms can also be tailored for more short-term missions. Many possible propulsion concepts can be used to generate a few milliNewtons or less and the ESA project singled out five i.e.

1) free molecule microresistojet (FMMR) that are easy to machine and robust…' ideally suited to attitude control'
2) chemical propulsion scaled down
3) cold-gas thrusters 'among the smallest rocket technology available today'
4) alpha-thrusters that 'permit fine tuning…in the range nano-to-micro-Newtons… coupled with much larger thrust when needed'
5) field effect electric propulsion (FFEP) 'characterised by a very low thrust'

Beside for the Alpha thrusters 'the technologies needed for these systems are currently available in Europe' (pages 175-176). The alpha-thruster is a very old concept going back to the beginning of the nuclear age. In short nucleotides – Curium-244 is suggested as 'the most suitable' (page 183) – are converted to a force on a sail. In 1995 the late interstellar pioneer Bob Forward outlined a 'deep-space radioisotopic sail' concept that could form a long term aim for the discussed ESA radioisotopic power generation program at present focused on power for surface landers. A more near-term suggestion is to reduce the 50% weight in a chemical micro thruster that is made up of microvalves.

Somewhat surprising after a listing of many possible applications for smaller satellites is the conclusion that telecommunication constellations will be the driver 'in reducing spacecraft size and cost' (page 198).

With present trends it appears that many Earth supporting space systems will form part of sensor webs and ubiquitous computing now being talked about in civil applications as well as systems for security and intelligence. The space community underestimated the impact of the integrated circuit once no humans needed to change valves and it would be very sad indeed if semi-conducting developments got underestimated twice.

Next up in Chapter 9 is 'Solar Thermal Propulsion for Upper Stages'. The reason for inclusion is clear: 'the relatively high-specific–impulse performance (700-900 seconds) compared with chemical propulsion…trip times of some 30 days for a Low Earth Orbit to Geostationary Orbit (LEO-GEO) transfer can be realised' (page 202). In the USA a private group Iostar is working on a nuclear concept to serve the same transfer market, but with its public acceptance issues perhaps solar thermal combinations will be tested before nuclear. In any case for solar thermal 'a less demanding first operational interplanetary mission is well within reach in 2014' costing '…less than €50 million in the next five years' (page 221).

Chapter 10 is a review of 'Electric Propulsion Systems' performed by Centrospazio/Alta of Italy as part of the ESA Propulsion 2000 project. During the first phase four concepts had been 'deemed by ESA worth of attention' (page 223) i.e.:

- high-power gridded ion thrusters
- high-power Hall-Effect Thrusters (HPHET)
- high-power applied field magnetoplasma dynamic thrusters (MPDT)
- double stage hall-effect thrusters (DS-HET)

The term 'high-power' here is below 10kW compared with the use of the term in nuclear applications where it means 100kW up to MegaW. Gridded ion thrusters being selected for the NASA Jupiter Icy Moon Orbiter mission is one, if not the most, studied especially in the USA and the UK. Hall Effect systems have been developed in USSR/Russia but 'given the extreme complexity of some phenomena…it has been the extensive experimental work that has paved the way…This work posed the bases of scaling laws, that resulted in designing families of thrusters of varying power levels…breakthroughs in thruster performance and configuration could be achieved only through procurement of new design tools' (page 250).

The Field magnetoplasma dynamic system 'peaks at power roughly 100 to 1,000kW and above. The lack of space power (but also of laboratory power!) in this range has prevented MPDT to be developed other than as laboratory models' (page 257). Jet Propulsion Laboratory developed such a system called Lorentz force accelerator (LFA) which was tested at the Moscow Aviation Institute (MAI) and some work on gas-fed systems are being done in Germany and Italy. The final concept – double stage Hall–Effect Thrusters – was developed in USSR/Russia and regarding so called two-regions system in Japan.

While this chapter is central and illustrates well the importance of electric propulsion for the future, it appears to have been cut with no final conclusion or roadmaps. The many tables and the bibliography make it however important as a source.

In contrast to electric propulsion it is not immediately apparent to the reader why a generic technology 'Superconductivity' is allocated a chapter (Chapter 11). Some hints are provided like links to the Superconductivity European Network but with the main space application provided being 'human interplanetary missions' (page 310) the chapter decision remains unclear. This is even more so since superconductivity is claimed to be '*the* enabling technology of future nuclear-electric propulsion systems' (page 303 – emphasis in the original).

Chapter 12 is concerned with a nuclear concept developed by one of the 1984 Nobel Prize Physics recipients Carlo Rubbia. It turned out that Yigal Ronen at Ben Gurion University, Israel, had been thinking along similar lines and in 2000 – a year after the Rubbia presentation – Ronen's team 'showed that the metastable isotope 242m Am could speed a spacecraft from Earth to Mars in as little as two weeks' (page 315). This possibility is due to the observation that the mentioned isotope 'can maintain sustained nuclear fission even shaped as a metallic film less than a thousandth of a millimeter thick' (page 315). Hence the traditional fuel rods needed for uranium or plutonium fission are no longer needed. However the concept having been investigated in Italy from 1999 was stopped in 2004 'after completing the feasibility study on its proposed test facility' (page 316). At the time of writing (2006) no further information was available from Israel. Any development of such a new fission type is up against advocates of other more mature fission technologies. Even so 'new, light and compact' – MegaW per cubed meter '…reactors that can be built in months rather than years might develop into a large market for terrestrial civilian and military applications' (page 317).

The next chapter provides a 'prefeasability analysis of VASIMIR (variable-specific-impulse magnetoplasma rocket) '…developed at NASA under the leadership of Frank Chang Diaz' (page 333). The analysis was performed by the Advanced Space Propulsion Laboratory at NASA Johnson Space Center but is under the name Alessandra Negrotti in the book. The main focus is a preparation for a 25kW test on the International Space Station. The VASIMIR concept can be traced back to nuclear fusion mirror machines and to the 1970s but more recently at NASA Johnson Space Center and the VX-10.The next step VX-200 (a 100kW fully superconductive flight like device) should be in test since 2007 (the chapter is from 2005) and a solar powered VASIMIR aimed for flying 'by the end of 2010' (page 349).

From a test and development program the book moves on to 'laser propulsion systems'. Like in the chapter on electrical propulsion much technical discussion is provided and here we have a development plan. The problem is the energy levels involved. Even testing 20MegaW for a test diameter of two metres is in an energy range that makes governments nervous. For Europe interest appears to be low. In fact, '…the work done in Germany by the authors of this study has been financed by the…U.S. Air Force' (page 384). Hence the final conclusion to this very well digested chapter: 'If the EU does not take any steps, it will neither become competitive nor be an interesting partner to other nations interested in this type of propulsion' (page 403). Perhaps the air platform demonstration of a MegaW class laser in the USA will activate the European policymakers?

Chapter 15 'Mass Accelerators: Maglev and Railguns' return to a future of mass production of very small satellites. Or alternatively 'this technology will play a major role once the Moon begins to be colonised and a lunar base begins to export certain classes of lunar goods to Earth'. It is difficult to expect any of those futures before 2020.

The final propulsion type to be investigated is discussed in Chapter 16 'Solar Sails – Propellantless Propulsion for Near- and Medium-Term Deep Space Missions'. The idea to transform the momentum of solar photons into propulsive force is not new but it was only in 2005 that the concept was ready for a flight test. It failed due to a 'malfunction of the launcher, a converted Russian nuclear submarine missile' (page 428) and it is claimed that no real technological problems exist for small sails made by aluminium-coated plastic films. For very large sails (up to 100m) much material development is needed as well as 'developing autonomous sailcraft navigation and attitude control; dealing with short timescales for attitude maneuvers in planetocentric orbits …' and more (page 447). The advantage of solar sails for future missions are so many that the claims should be tested as soon as possible, beginning perhaps with the ground tested 20 metres by 20 metres sail at the German Aerospace Center.

Finally the previously mentioned chapter on 'In Situ Resource Utilisation'. With a focus on humans and the given 2020 timescale the relevance is at best unclear. The point is accepted since 'vaster resources are necessary to perform realistic architectural study and subsequently to identify critical technologies or items and to recommend their development' (page 474).

The book would have benefited from a chapter on the ESA Exploration Strategy (Aurora) since it is within this activity that advanced propulsion not related to Ariane will likely be developed. Aurora is mentioned but the dark figure (page 475) makes it difficult to read and the meaning of 'EU decisions' (page 476) is unclear since it is unclear if the EU understood a programme like Aurora. A chapter ending the volume by pulling the t echnical segments together would significantly increase the value. In its absence it is tempting to have a try:

1. Until a political decision is made to move towards winged launchers, the existing solid and liquid combinations will remain the core propulsion development activity.
2. Nuclear systems will remain on conceptual and component level until a need can be identified that will pay for development. This need could be terrestrial need for electricity, deflection of near earth objects or faster missions from earth.
3. The most likely innovative introduction will be an in-orbit system including microsystems, solar sails and even nuclear propulsion.
4. Some technologies should be included in the EU-ESA integration including beam-based propulsion. In this discussion injectors for tokamak fusion should be added to compensate for high power lasers at present. Further topics in such integration should be the so called Rubbia's Engine where testing is essential for progress and much knowledge exists within EU-EURATOM projects.
5. Advanced propulsion is the battering ram for new space applications. For this reason a pool of possibilities must be nurtured that every propulsion engineering generation can dip into and argue about.

In short, propulsion must be better understood and volumes like this make a contribution toward such understanding.

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