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Short communication

A civil super-Apollo project in nuclear research for a safer and prosperous world

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ABSTRACT

Humankind is confronted with a "nuclear stewardship curse", facing the prospect of needing to manage nuclear products over long time scales in the face of the short-time scales of human polities. I propose a super Apollo-type effort to rejuvenate the nuclear energy industry to overcome the current dead-end in which it finds itself, and by force, humankind has trapped itself in. I propose a paradigm shift from a low probability of incidents/accidents to a zero-accident technology and a genuine detoxification of the wastes. A 1% GDP investment over a decade in the main nuclear countries could boost economic growth with a focus on the real world, epitomised by nuclear physics/chemistry/engineering/economics with well defined targets. By investing vigorously to obtain scientific and technological breakthroughs, we can create the spring of a world economic rebound based on new ways of exploiting nuclear energy, both more safely and more durably.

1. Nature of the problem: societal risk and nuclear energy hazard

Human development of nuclear materials for civil (as well as military) uses has created a singular situation. Here the term "singular" is taken in the strong sense of a unique situation with no equivalent, ever. The singular situation is that humankind has put on herself the task of husbandry of nuclear materials and of the waste of civil and military uses for centuries, tens of millennia and up to millions of years, depending on the nature of the radioactive elements. Indeed, by-products of a reactor last for hundred years (e.g. Cesium-137 with a half-life of 30 years) to hundreds of thousand of years or even millions of years (Plutonium-239 with a half life of 24,000 years to Technetium-99 with the largest fission product yield of 6% for thermal neutron fission of Uranium-235 among long-lived fission products with a half life of 211,000 years).

Consider that these time scales, during which humankind needs to babysit these nuclear residues, are comparable to, or larger than, that of the lifetime of the human species 'homo sapiens', usually dated to have emerged in his modern anatomical form about two hundred thousands years ago! It is essential for the biosphere, and in particular for human health, that the artificially concentrated and man-made nuclear materials are not entering the biological cycles. The singularity of centuries, tens of millennia to the million-year time scales of required human management stands in stark contrast with all other activities involving time scales of decades to centuries – at most, even in the worst chemical pollution cases. Even the long time scales involved in global climate change are dwarfed by those resulting from human nuclear activities.

It is thus essential to frame the issue of nuclear energy within the dynamic context of society. Human societies are in continuous evolution, formation, aggregation, fusion, consolidation, disaggregation, collapses and so on. Human societies are punctuated by transitions taking the form of revolutions, civil wars, conflicts, ethnic collisions and instabilities [1]. The typical time scales of human societies are decades to centuries, at best [2–4]. No empire, nation or society has ever been stable and without major conflicts over time scales of more than a few decades. Even the most stable society evolves. And a large body of evidence shows that these evolutions often occur abruptly rather than through smooth transitions [5]. In other words, a large body of works on comparative history [6] and, more recently, on geopolitical dynamics, show that human societies are not stable but are prone to crises and sudden mutations.

Think of the crisis in Europe in the early 1990s, leading to the breakup of Yugoslavia following a series of political upheavals and inter-ethnic Yugoslav wars affecting primarily Bosnia and Croatia. Consider the so-called Arab Spring started in December 2010, that destabilised regimes that had been stable for decades – such as Tunisia, Egypt, Libya, Mali, Syria and Yemen – and with major protests in a host of other Arab countries. Reflect on the situation in Pakistan, Bangladesh, Iran, Thailand, in many African countries and in South America; the political and social world is very far from

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stable, even on a time scale of years to decades. And what about the growing inequalities in the Western world in the last decades characterised by a progressive but steady impoverishment of the bottom 99% of the population [7], which may breed again new large scale instabilities with uncertain and perhaps extraordinary consequences?

Humankind is thus faced with the problem of managing sensitive man-created wastes over much longer time scales than the lifetime of ephemeral human polities. In fact, the development of nuclear energy has been based on an implicit formidable bet that human societies will be sufficiently stable, solid, and reliable to put nuclear husbandry at a suitable priority level, and at all times, in order to avoid catastrophic singular events or a progressive alienation of our biosphere. Nuclear energy is a recent phenomenon, whose development covers no more than the last 60 years or so. In this time, the major powers have been on the brink of total mutual destruction during the Cold War. Many argue that the military nuclear threat has been the very engine of stability in the Western world, following two debilitating (except for the US) world wars. But what about the more than 140 countries on this planet that are deemed non-democratic and exhibit various levels of potential or rampant instabilities? And, when examined from a historical perspective, it may be no less than a heroic claim that societies that are now seen as stable will not transform into locii of instability.

According to another narrative, the end of WWII, followed by the bipolar world order organised around the two superpowers resulting in the Cold War, led to an illusion of stability – a dream that social and political systems have evolved towards higher levels that could ensure better outcomes to resolve human conflicts. However, History suggests that betting on human peace and stability may be dangerous. Perhaps, the situation is becoming even more uncertain, with the progressive transition to a new regime where scarcity of natural resources and essential commodities and the competition for vital space will shape the new densely populated world order.

How is it possible to ensure that teams of skilled technicians will dutifully continue their routine maintenance of key nuclear facilities and waste storage sites in the presence of a local revolution, conflict or war threatening their families? What if Saddam Hussein, exasperated after losing power, had a nuclear power plant (NPP) to make critical (by simply destroying or incapacitating the cooling systems), rather than burning oil fields? Even worse, in the event of severe conflicts between nations, NPP and other critical infrastructures become prime targets in the goal of crippling the enemy. As a recent vivid illustration, during the Ukrainian civil war, there was active social media activity concerning the calls to attack the Zaropozhskay NPP (the largest NPP in Europe and the fifth largest in the world), which is 200 km from the war zone. In February 2014, operatives of the Right Sector were arrested by guards of NPP when trying to infiltrate them, forcing NATO nuclear specialists to check that all Ukrainian NPPs have adequate protection measures.

Another dimension of the singularity of nuclear energy is the extraordinarily large impact that a single accident can have at the worldwide level. There are currently more than 440 nuclear reactors in operation and more than 60 under construction worldwide. For all, one cannot exclude the possibility of another accident involving a partial meltdown of the reactor of a large NPP, with a significant fraction (say 5–20%) of the reactor contaminating the atmosphere, ocean and/or Earth soil. Our estimates show that just one event has global measurable consequences [8,9]. Supposedly impossible scenarios (according to industry-standard Probabilistic Safety Analysis risk estimates) such as Chernobyl and Fukushima [10] can be taken as the basis to imagine others, whose impact would be in the range of tens of trillions (of dollars, euros, Swiss francs, etc.) with lasting consequences in the form of major zones of uninhabitability [8,9]. Think for instance of the real-estate value of New York City, USA or of Zurich, Switzerland, both of which are rather close to an operating NPP and would become uninhabitable in exceptional and extremely unlikely – but possible – scenarios. Hence, the management of the nuclear energy industry should be considered as a public good, where any accident or misbehaviour in one major NPP has externalities over the whole planet. Most relevant to Europe, the Chernobyl accident had – and still has – significant environmental, health and financial implications. Furthermore, there is no guarantee that radioactive materials will remain hermetically enclosed in the concrete sarcophagus in the future. This is a Damocles sword hanging over the head of large European populations for many generations. Thus, even in stable society, nuclear risk is still high [8,9]. The official industry and political position is a combination of dangerously underestimating risk, and being disingenuous about it to the public. Clearly the risk needs to be understood and publicly acknowledged before there will be public support for addressing it.

Even in supposedly stable and efficient societies, it is doubtful that we can count on the reliability of human managed organisations to ensure a safe nuclear stewardship. In his study of the safety of the US nuclear weapons command organisations, Sagan [11] provided numerous examples that the organisations one may have surmised to be those with the best safety record are in fact plagued by failures and accidents, due to political infighting, organised deception, normalisation of errors, reclassification of failure as success, and conflicts over short-term interests. In a recent book, Schlosser [12] goes further by reporting in details on known accidents with nuclear weapons that have been regularly taking place since 1945. Centering on the Damascus accident of 1980, an explosion in a Titan II Inter-Continental Ballistic Missile housed in Damascus, Schlosser documents a litany of nuclear accidents revealing the past, present and future vulnerability of the exceedingly complicated technical systems that are nuclear weapons, embedded within layers of bureaucracy and subjected to the continuously changing nuclear policies of the politicians. The civil nuclear energy industry is distinct from the nuclear weapon organisations, but for our purpose they both share a number of important characteristics: (i) they deal with the same high energy density of nuclear physics at 1 MeV; (ii) they deal with extremely complex systems, interfaced with and managed by fallible human operators embedded in imperfect institutions; (iii) they are exposed to the changing whims of politicians, themselves reacting to the volatile public opinions.

And there is the controversial economics of nuclear energy (see e.g. http://www.world-nuclear.org/info/Economic-Aspects/Economics-of-Nuclear-Power [13]). On March 4, 2015, the French Areva nuclear group announced record losses of 4.8 billion euro for 2014. One may wonder whether and when cost-cutting will impact security measures and reduction of competent personnel? Most of the 440 NPP in operation are over 30 years old and will require increasing investment to ensure safety, not to speak of the cost of decommissioning a NPP, which may turn out to be roughly on par with the cost of building it.

In the best case scenario (in the absence of conflict and regime change), according to a detailed statistical study of the most complete available database that is 75% larger than the previous best dataset on nuclear incidents and accidents, Wheatley et al. [9] found that we still have a 50% chance that, in terms of costs, (i) a Fukushima event (or larger) occurs in the next 50 years, (ii) a Chernobyl event (or larger) occurs in the next 27 years and (iii) a TMI event (or larger) occurs in the next 12 years. Fig. 1 provides a precise statistical quantification of these statements. This suggests an intrinsic instability of the nuclear energy industry. Together with my other argument on the instability of societies, the diagnostic is inescapable: an unstable industry in an unstable world.

I then ask how can the reliable management of nuclear risks be achieved over the required time scales of tens of years, hundreds