SSD

SCIENCE FOR A SUSTAINABLE DEVELOPMENT

NUCLEAR ENERGY GOVERNANCE

DELIVERABLE 4.1

SEPIA PROJECT

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SCIENCE FOR A SUSTAINABLE DEVELOPMENT (SSD)

Energy

Deliverable 4.1

NUCLEAR ENERGY GOVERNANCE
SEPIA PROJECT

SD/EN/7A

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SEPIA in short

The goal of SEPIA is to make accessible and discuss the feasibility of important aspects of sustainability assessment (SA) in the context of Belgian energy policy, in order to identify consensus and dissent in the possible SA design among different stakeholder groups, and thus to provide the basis for an SA procedure adapted to the context of Belgian energy governance (being embedded in a multi-level governance structure). The study explicitly acknowledges the socio-political and normative background of the debate on energy issues and choices, including sustainable energy.

The SEPIA research unfolds in four phases: (1) methodological preparations (SA, criteria & indicators for sustainable energy, foresight methodologies, participative approach) (month 1-6), (2) development of representative long-term energy scenarios for the Belgian context (month 7-18), (3) assessing the performance of the energy scenarios with the aid of a stakeholder panel (supported by an energy accounting model (LEAP) and a multi-criteria group decision support tool (DECIDER)) (month 19-30), (4) communication and dissemination of results (month 31-36).

Work is divided in seven work packages: (1) methodological framework, (2) future study of the Belgian energy system (horizon 2050), (3) integrated value tree for sustainability assessment, (4) case-study on Belgian nuclear energy policy, (5) multi-criteria decision support for sustainable energy policy, (6) analysis & recommendations, (7) outreach.

The project is conducted in the framework of the BELSPO project "Science for Sustainable Development". It runs from January 2008 till December 2010. The research methodology is interdisciplinary by attempting to integrate insights on energy system dynamics stemming from engineering, economics, policy sciences, sociology and ethics; while at the same time being attentive to the context-dependent nature of such knowledge (by trying to incorporate stakeholder insights).

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Disclaimer & Preliminary Remark

The know-how and experiences reflected in this report are gradually build up during different projects and expertises. Due to 44 years of active personal implication in nuclear practise and in decision making (DM) at different levels some aspects of this research can be characterised as action research. The reporting was enriched by discussions with a variety of relevant actors at different levels of policy making. Elements are integrated in the analysis not only for historical data clarification but also for vision development without disclosing any delicate company information not yet accessible in open literature. As such the report is the result of literature follow-up, teamwork, varying scientific methods (technical, social, historic, etc.), active implication, involvement experiments and reviews over a long period.
As interaction of disciplines the research also aims to be trans-disciplinary or problem solving oriented.

The author has no longer any management responsibility in the nuclear sector[1] at the date of publication of this report, neither any financial binding to the sector.
In advisory mandates[2] to competent authorities he is submitted to periodic declaration of potential conflicts of interest (procedures Superior Health Council) and he agreed to follow ethical guidance of application (Art 31, BVS/ABR). In this context statements can be considered as impartial.

The treatment and editing of factual elements was closed November 4, 2010.

The author acknowledges critical input from the steering group on a preliminary report in 2009.
The valuable methodological and editorial steering from Erik Laes during the whole project and the review of the draft report of 1/11/2010 by Gaston Meskens was appreciated very much. Remarks were integrated as much as reasonably achievable within the contractual scope and constraints of SEPIA.
The author thanks his collaborators Fre Maes and Jean Hugé for valuable discussions and editing input.
Finally he appreciated periodic input from and discussions with the coordinator Aviel Verbruggen during the project as well as the many years before.

This report is the sole responsibility of the author and the views therein do not necessarily reflect those of other members of the SEPIA research group. Considering the limited scope of this task in SEPIA and due to the limited human resources capacity available this work has not the ambition to reflect a complete picture of the subject. Mistakes or misinterpretations are the author's responsibility.

[1] President of Belgian Society for Radiation Protection (professional scientific organisation, IRPA affiliated) from 12/2008 till 3/12/2010; IRE member of the board of administrators till may 2009, chairman of the section Radiation of the Belgian Health Council (till October 2010)
[2] Member of the scientific council of FANC/AFCN; member of the EC group of experts (called committee ART 31 EURATOM, advising the EC on Radiation Protection; member of the College of the Belgian Health Council (nominated expert), expert in the Belgian delegation in UNSCEAR (UN high level advisory group on the effects of ionising radiation)

I. Summary

Nuclear energy is a thoroughly divisive issue in Belgian energy policy. Notwithstanding different opinions on the future of nuclear energy in Belgium, one cannot deny the fact that nuclear energy has dominated energy system development in the past, and that energy systems in general show a great inertia towards changes. Therefore, in this work package, a critical assessment will be made of past, present and future nuclear energy policy options in Belgium taking into account the international development context, characterized through pathway analysis.
Strengths and weaknesses are qualitatively evaluated and screened in a framework of generic sustainable development principles: integration, precaution, equity, stakeholder involvement and global responsibility. This was inspired by the PhD work of E. Laes (Laes, 2006) and by the transition exercises of the Belgian Federal Planning Office. Attention is paid to numerous criteria through a clustered factor analysis. Technological options, energy and resource use efficiency, environmental pressure and health risk indicators, accidental risk, waste production, proliferation risk, ethical options, acceptability and involvement and finally perception and distribution factors are looked for.
The results of this work package can serve as an input in the scientific debate on societal transformation towards sustainable energy supply systems, highlighting the role of sustainability assessment exercises in transition management.

The report is structured around 4 'building blocks', each of them describing development pathways centered on 4 subsequent 'generations' of nuclear technology: Gen II (i.e. the first wave of commercial nuclear power plants mainly built in the period between 1965-1990), Gen III (i.e. the new wave of commercial nuclear power plant designs, currently either being built (e.g. in Finland and France) or planned to be built (e.g. United Kingdom, the Netherlands), Gen IV (innovative nuclear concepts developed in a global initiative led by the United States, generally expected to be commercially available between 2030 at the earliest and 2100, and Gen V (fusion power at the horizon 2070), which could end to compete with Gen IV.
The DPSIR (Driving forces – Pressures – States – Impacts – Response) framework is referred to discuss environmental, social, institutional (regulatory) and economic impacts for each of the 4 pathways.
For the 'Gen II' pathway, lessons for present and future decision making in the new context of sustainability are drawn on the basis of the ViWTA nuclear controversy analysis (Laes et al., 2004)[3]. The historical analysis essentially concerns reactors and fuel cycles of the first and second generation of nuclear energy development in Belgium, including the first inventory of nuclear R&D costs.
Next to this, the report also considers siting constraints of nuclear installations in a densely populated region, and the long-term requirements and provisions for radioactive waste management and dismantling of nuclear installations. Both of these issues are important elements to take into account in a discussion on the future acceptability of nuclear power in Belgium.
'Gen III' pathway developments (mainly centered around the deployment of the new EPR reactor) are analyzed in the present context of European liberalization of energy markets and national attempts to phase out nuclear energy or to replace it by Long Term Operation (LTO), the Suez/FANC strategy development.
This work is also discussing the ongoing Finnish experience on Gen III reactor construction (and the reasons for delay) and the French scale challenges in world competition.
Siting and regulatory constraints are also discussed for a possible Gen III pathway in Belgium as well as societal impacts. The regulatory constraints and progress at EC level are analyzed with lessons learned from the Belgian regulatory crisis (Federal Agency for Nuclear Control (FANC)).
Attention is given to new risks such as terrorism and serious reactor accidents beyond design.
For the future, the long term fusion option (Gen V) as well as the generation IV US/European set of recent nuclear developments are considered qualitatively with particular attention for the limited framing of sustainability by the nuclear sector. The Belgian contribution in the pipeline: the MYRRHA project of SCK is assessed briefly.

[3] published by ACCO in (Laes,2007)

The fuel cycle time horizons for partitioning & transmutation options between 2030 and 2100 (long-term) and their relative impact on nuclear waste management are discussed. Gen IV takes into account new proliferation challenges as well.
Amongst other references it is noticed that the prospects of the European Energy Delphi exercise (EURENDEL, 2003) and of the Belgian Federal Planning Office differ considerably from foresights from the nuclear sector. No systematic comparison is made within the limited scope of this study.
Low energy efficiency of centralized electricity production options is compared to total energy concepts which also offer alternative nuclear options for future. The marginal attention given in research financing in Belgium for small-scale high temperature reactors compared to the controversial fast neutron reactors is symptomatic and proposed for further investigation. Moreover it could allow to associate possible perspectives of our energy intensive process industry and of the hydrogen economy. This work aims to contribute to the application of sustainability assessment to nuclear energy in the future at least at the same level of depth and impartiality as for other energy supply options.
Finally nuclear consult and support was given to the researchers in other work packages of SEPIA and in particular to participative exercises when needed.

The answers on the research questions for this part of SEPIA are briefly summarised:

Could nuclear energy bring a potential modest contribution to the management of climate change without affecting sustainable energy demand? ***Yes but not necessarily if it contributes also to decreased energy efficiency. Therefore more attention should be given to total energy system development (HTR) and downscaling of unit size.***

Can the nuclear sector (with all its inherent complexities) be 'shaped' by the requirements of democratic functioning, confronted as policy making is by an 'existential crisis'? ***It seems very difficult for the present functioning of policy making to adequately assess nuclear energy options at the relevant levels, beyond interests and lobbying, to set the required conditions and to direct nuclear developments in a sustainable way. The integration and improvement of the EURATOM treaty is required with a larger role for the EC to be able to realise sustainable nuclear developments.***

How to clarify the challenges for the nuclear sector to meet the requirements for sustainability? ***The requirements of the 5 sustainability criteria, integration, precaution, equity, involvement and global responsibility as applied in this study, have another much larger dimension than the objectives set by the nuclear sector for contributing to sustainability, limited by referring only to climate, resources and the environment.***

Are the real challenges still nuclear waste, accidental reactor risk and proliferation or are technological vulnerability, siting constraints, availability of resources, employment perspectives again key issues?
The three challenges will continue in increasing priority to impact on acceptability as long as equity conditions are not met. The other factors could be at the centre of public attention again with possible boomerang effects, especially when historic events are kept in mind. Transparency of the sector is not yet structurally realised and communication approaches call for evaluation in the growing challenge of manipulation of information.

What are the environmental and recurrent health challenges or uncertainties put forward by recent studies? ***Genetic susceptibility and bystander indirect effects of ionising radiation beyond cancer.***

Finally, are the basic safety standards for nuclear protection feasible to protect environmental systems as could be required for sustainable development?. ***Not yet as they remain mainly anthropocentric. The extension to selected fauna and flora is not an ecosystem approach. Abstract health indicators only relate to virtual average individuals and not to biodiversity within ecosystems***.

II. Nuclear energy in search of sustainability

The follow up of nuclear dynamics over the 3 project years is based on personal experience in advisory processes for nuclear decision making, on analysis of cutting-edge conferences in the field of nuclear science and engineering, on insights of privileged actors and on some critical review of external sources. (e.g. Nucl. Engin. Int., IAEA News, Intern. Press Reviews). The interaction with non-nuclear experts (such as IPCC experts) has broadened the scope and was valuable. Periodic discussions and feedback with the project team fertilized ideas on assessment methodologies in progress (sustainability assessemnt, precaution analysis) and participatory experiments (e.g. public consultation on the NIRAS nuclear waste plan, see also the SEPIA contribution in annex 2 by J. Hugé et al, 2010).

During the course of the project the controversy on the nuclear phase-out continued at the Belgian national level, where the intention of the government to prolong the lifetime of the 3 oldest nuclear power plants (NPP’s) beyond 40 years, as foreseen in the phase-out law was halted by the Belgian political crisis of 2010. The steam generators of Doel1 were however authorised for replacement, amounting to an investment of 100M€, difficult to write off in the four remaining years (according to the phase-out law).

In Sweden and Germany the phase-out is being revisited and presented as a transition to a non-nuclear future, responding to the anti nuclear movement which is also active on a larger scale in Germany. Meanwhile the French nuclear electricity sector (EdF, AREVA, both controlled by the French government), was charged with Gen III reactor development (EPR AREVA) at Flamanville and Penly, and faced competition challenges at the European level. It was assessed for restructuring (Roussely Report, 2010). France’s second-ranked utility (GDF-Suez) abandoned participation to the Penly project while it is now controlling the Belgian NPP’s. It has set up a strategy for prolonged Gen II lifetime operation of 60 years and possibly more in accordance with the Belgian regulatory agency (FANC) and has shown interest for Gen III projects in the UK and the Netherlands.
New projects of countries considering Gen III development (UK and the Netherlands, Gulf States, China,…) are driving up competition among reactor vendors. The US nuclear reactor industry gives priority to smaller Gen II-III projects (AP1000) and even to small-scale nuclear developments (Westinghouse). Belgium has launched considerable research ambitions in Gen IV with France which has a leading role in most of these nuclear R&D strategies. USA, EU, China, Japan and Russia contribute to this development. Their nuclear ambitions at present are however kept at a relatively modest level of 20 to 40% of electricity production, half of the present Belgian/French level (54/76%). The country with the highest growth in electricity consumption levels (>10%/y), China, is diversifying electricity production while developing total energy nuclear concepts as well (high temperature reactor (HTR)).
The so-called nuclear renaissance strategy (Gen IV) for the future on national, European and international level is “déja vu”. Clever political marketing, is combined with an established ideology of grasping 'opportunities for business’. It is based on fast neutron reactor technology and advanced reprocessing, which already caused controversy more than two decades ago, particularly in Belgium and the USA. The latter still hesitates to restart an advanced reprocessing pathway for proliferation reasons, given the fact that uranium and thorium resources are projected to be abundantly available for more than 100 years.

In Belgium it contrasts with the official phase-out agenda. Governmental budgets for research were allowed to be directed to support controversial media campaigns of private interest cartels to change the law[4]. The discourse of nuclear proponents contrasts more than ever with the slightly decreasing but still relevant lack of public trust.
Siting prospects of new NPP's at the border and the subtle marketing actions of nuclear industry against the nuclear phase-out seem on the contrary to awake opponent movement in public debates.
This evolution is analysed in its historical context and in the frame of sustainability principles.

[4] http://www.nuclearforum.be/

III. Sustainable development principles as guidelines

• Pathway analysis methodology for integration in SEPIA

A pathway in the SEPIA context connects a particular vision on a “sustainable” energy future with the current situation by establishing the social, institutional, cultural, technological and economic developments necessary to achieve that vision. Multiple pathways towards one vision are possible; they need to be coherent with the objectives of that vision. **Pathway elements** build a pathway. They constitute of policy choices, financial means, behavioral changes, events, etc. that, brought together, establish a "pathway" from the current to the envisioned future. This concept is also applicable to past visions persisting in the present, as illustrated by the historical analysis on the Gen II pathway aiming now to extend its use to (at least) 2045. It constitutes a first building block in the nuclear WP of SEPIA.

> Ex. The choice of the PWR reactor in the past for nuclear electricity generation was the core of a pathway towards an ’all-electric’ society. Reprocessing and spent fuel storage were two alternative pathways elements, the first addressing a century of recurrent recycling operations. To realize that future a series of industrial, institutional (establishment of SCK, later NIRAS) and economic developments (high capacity transboundary grid, electricity intensive industry and heating applications, plant life extension (PLEx)) were and are required to achieve and extend that vision till 2050.

III.1 Clustered Factors

For the aim of development of the concept in SEPIA, we selected a non-exhaustive overview of clustered factors in 5 groups (A to E), which shape pathway elements and are or will become relevant for understanding the dynamics of investing in nuclear power:

A. Reactor technology (NPP)

- Decision Making Process (DMP) - from *fait accompli* to phase-out
- Siting NPP (at the borders) - Thermal pollution - Electricity grid implications
- Safety management - accidents - safety culture
- Plant life extension

B. Nuclear fuel

- Complexity of the fuel cycle industry
- Role of nuclear R&D
- Transitions in fuel management
- Nuclear waste management

C. Drivers of development

- Optimistic technological prospects
- Military interest and implications
- Electricity forecasts - economic perspectives

- Energy policy prospects at European level - EURATOM treaty

D. Regulation of nuclear technology - Role of the State

- Health and environmental concerns
- Authorisation processes and radiation protection control
- Environmental approaches and accident management
- Proliferation control

E. Social Interaction:

- Risk communication - Public perception - Transparency
- Safety at work
- Liability - Insurances
- Value systems

III.2 Basic principles of sustainable development

Five basic principles of sustainable development are projected qualitatively on the clustered factor analysis in the building blocks. They concern the required **Integrated Approach (I)**, a **Precautionary risk strategy (P), Stakeholder Participation (S), Equity (inter- & intra-generational) (E), and a Global Outlook (G).** These principles (I,P,S,E,G) form the backbone of the SEPIA scenarios, and were developed by Laes in his PhD (Laes, 2005). They are also applied in sustainable development foresight exercises by the Federal Planning Office (Fe, 2007).

I. Integration

- The **Integration** component of SD is considering how health, socio-economic impact, energy efficiency, environmental and knowledge factors are in harmony (**coherence**); this can be a thematic integration (UN: energy, water, etc.) or within a thematic line (sector integration). We consider in particular the **European integration as most relevant political dimension (**see **G)**

P. Precaution

- **Precaution** is seen as a strategy for dealing with uncertainty facing complexity. This should be done in an alert, careful, reasonable and transparent way (GR, 2008). It is based on UNESCO and EEA action rules, integrating for the nuclear context **uncertainties** on scientific and technological risks as well as **ambiguities** related to interests and ethical judgements in risk assessment. Interpretative ambiguity is a kind of cultural transition between normative ambiguity and uncertainty, which in relation to risk governance (GR, UN) can offer different justifiable interpretations of risk assessments; it requires structured **transparency in particular in risk communication and participative democracy (**see **S)**.

S. Stakeholder participation

- Stakeholder **participation** is striving for participatory democratic involvement of relevant actors, which is becoming inherent to precautionary risk governance. Criteria for governance have been detailed by the UN such as lawful, demand-led, consensus-seeking, fair and open, and publicly accountable governance.

E. Equity

- **Equity** regards **distributive** issues and responsibilities across borders (i.e. trans-boundary justice) and time (i.e. trans- generational justice) and anticipates on public needs, taking into account the crucial role of the common good regulating the use of technology and the management of resources (role of the State).

G. Global responsibility

- **Global responsibility** considers the global (market) reality requiring coherence, regulation and collaboration in transferring differentiated responsibilities at local or regional level. In the Belgian context the most relevant level of collaboration and regulation in the face of globalisation is again the European dimension.

III.4 Building blocks

The four building blocks are:

- **The historical analysis** of major points of controversial social interaction in **Generation I** (i.e. the early research reactors) **and Gen II reactors,** complemented by a **DPSIR framed analysis** of the nuclear sector as a whole, also taking into account the **affiliated** nuclear **renaissance strategy**. This allows us to better position some factors of the past in present decision making by making use of indicators for technical, health, environmental and local economic trends. Value-based options in Gen II are pointed out, questioning the significance and evolving relevance of a respect of the law in the market dimension.

- The **present developments of Gen III reactors and nuclear technological developments of fuel management worldwide;** a critical follow-up shows new constraints regarding construction cost, competitiveness, the role given to IT steering (control-command) and authorisation controversies in international projects. Particular attention is given to the feasibility and coherence of sustainability criteria application and to the future impact of our growth paradigm. This exercise critically assesses the potential of the Gen III pathway's as transition processes towards sustainability.

- **Gen IV evolution** through **international network progress follow-up.** At the European level the recent European Nuclear Energy Forum approach is integrating some of the Franco-American strategic options and related industrial and scientific marketing. This follow-up provides a clear analytical focus on the Belgian platform for participation in GIF (Gen IV Int. forum), the NEA evaluation of MYRRHA and the constraints at the regulatory level. Policy coherence with other nuclear or non-nuclear measures and historical consistency is looked for.

- **Fusion prospect (Gen V)** and its gradually started economic implementation will be reviewed briefly in the context of ITER at Cadarache, France and of the future prototype in Japan. Particular attention will be given to the budgetary problems, the transparency of participation processes, environmental relaxation measures proposed for tritium releases by France and to some nuclear waste consequences. Possible competition problems in R&D strategy between the mega projects of fission and fusion in future is given due attention.

Cross cutting is the analysis of underlying values and culture in the interaction between nuclear technological options and the wider societal context through cluster E. An attempt is made to identify some implicit or explicit value judgements and conflicting interests. New risk data could challenge health criteria, but aim in particular at a distributive justice of benefits and disadvantages (intra-generational equity). For nuclear waste management inter-generational equity considerations play a particular role. New policy priorities of nuclear waste reduction, neglected in the past, will also be considered on consistency. The impact on present options (retrievability, transmutation, final disposal, robustness (technological and social) is assessed. An attempt by the Dutch ethicist Benham Taebi to assess these policies in a theoretical philosophical context of sustainability and trans-generational justice is briefly discussed. Finally we introduce the concept of transparency assessment, presenting new risk governance approaches and a model for risk communication on local and national level.

For each of the 4 building blocks or core technologies (I&II,III, IV, V), the mentioned clustered factors (A to E) are highlighted in bold and discussed individually or as cluster. The (dis)accordance with SD principles are discussed at the end of each cluster chapter, highlighted in italic, with a pictural global smiley classification, (☹😐☺) **,** as used by the Environmental Reporting (MIRA) approach of the Flemish Environmental Agency (VMM[5]). This is only applied for each cluster separated in the Gen II analysis, and globalised for the other pathways.

This reflective methodology allows us to indicate potential lessons for the future while checking present policy options. The approach allows us to clarify trends in governmental decision making, as well as in the role of industrial actors.
Our sustainability qualification is of course subject to interpretation and will provoke controversy in itself. This is however inherent to societal interaction where different interests are at stake. Our historical study has characterised this as a filtering process of robustness of argumentations.

Some reflections relate to the research questions or to problems posed during the SEPIA stakeholder and expert consultation. These are discussed in a final chapter VII.

Could nuclear energy bring a potential modest contribution for the management of climate change without affecting sustainable energy demand?
Can the nuclear sector (with all its inherent complexities) be 'shaped' by the requirements of democratic functioning, confronted as policy making is by an 'existential crisis'?
How to clarify the challenges for the nuclear sector to meet the requirements for sustainability?
Are the real challenges still nuclear waste, accidental reactor risk and proliferation or are technological vulnerability, siting constraints, availability of resources, employment perspectives again an issue? What are the environmental and recurrent health challenges or uncertainties put forward by recent studies?
Finally are the basic safety standards for nuclear protection feasible to protect environmental systems as could be required for sustainable development?

The approach for WP4 could help to put nuclear energy in a perspective of relativity or modesty instead of the polarised pro-con attitude.

[5] www.milieurapport.be

IV. Historical analysis Gen I & II

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- **Relevance of lessons learned during 50 years of nuclear energy controversy in Belgium**

IV.1 Pathway discussion regarding PWR[6]

> **Pathway:** *Pressurised water cooled thermal neutron reactor for guaranteeing centralised electricity supply(>50%) in Belgium by a French utility. 7 reactors operating on 2 river sites, connected to a European liberalised grid, fuelled with slightly enriched uranium from a diversified origin and linked to a complex fuel cycle industry under French control. Two main fuel cycle options in parallel: closed (MOx recycling) and open (spent fuel storage). Nuclear waste is taken over by the State for disposal in Belgium. Long term regulated reactor operation planning (>2045) in a dense populated industrial and traffic-intensive area where 65% of thermal energy is lost.*

An historical analysis of nuclear controversies in Belgium (Laes 2007), has been used to treat the nuclear decision making processes related up to now to this kind of generation II reactors and has focussed on 'hinges' in the social, cultural and political dynamics. The core of this Belgian Gen II option was and is the PWR, now essentially a French technology of American origin. Gen I gas cooled graphite reactors are only used for research purposes in Belgium (BR1) and are less relevant for SEPIA purposes. The operational record of PWR is not bad, producing electricity at cheap costs with high market prices due to depreciation in 20 years. All steam generators of this reactor generation had to be replaced. The last was Doel 1 in 2009-10. The investment of +/-100M € was made notwithstanding the phase-out law (which stipulates a closure of this plant in 2015); it was authorised by the government. The main present actor Electrabel-GDF-Suez is re-launching the plant life extension[7] of the 7 units now in a long term operation strategy, LTO[8], for continuing electricity production for at least 20 years after first phase-out planning. This means till 2035-45 or later which relates to the time scale of the 2050 SEPIA sustainability assessment.
This justification is not based on sustainability arguments but on safety improvements legitimated by international comparisons and network criteria (IAEA) within a framework created by the governmental agency FANC[9].
It contrasts with the Belgian law of 2003 foreseeing a reactor phase-out at the age of 40 years, meaning unit shut down between 2015 (starting with Doel 1) and ending in 2025, except when energy supply should be in danger. This highly controversial condition turned out to be in particular for the first three units(2015) more of a political intra-generational distribution conflict on financial compensations than an acceptability debate on balancing nuclear risks with the benefits of keeping open the 3 oldest NPP's longer than foreseen.

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[6] Pressurised Water Reactor(PWR) *(US-Westinghouse)*
[7] PLEx
[8] Preparing Long Term Operation for the Belgian Nuclear Power Plants, Electrabel-GDF-Suez, sept 2010
[9] FANC: Federal Agency for Nuclear Control, the Belgian nuclear regulator

A law theoretically reflects leading values in a democratic society but is also related to a temporary consensus of representing political families. Dynamic respect of the law as core duty was overshadowed by the polarisation of discourses on this nuclear phase out. The law here has not to be changed but can be interpreted in a rather arbitrary way. No clear value references are put forward in the consideration of security of supply which is paradoxically no longer a national competence in the electricity market. Politics and nuclear governmental agencies gave confusing signals. Since 2009 the FANC, the Belgian nuclear regulator is working out a strategy for the decennial revision of the Belgian NPP's from 2015 on, assuming a withdrawal of the law. FANC is not presenting an equal state of preparedness in case the law persists. An attitude which has been considered by some as non impartial since no comparison is made with alternatives. Reactor transition projects exist for Gen III in the Netherlands at the Borsele border site or in France, where the same utility Electrabel-GDF-Suez competes. But neither safety nor sustainability criteria have been comparatively considered with Gen II PlEx in that region.
In this building block some reflexions are already made on GEN III and IV technology and Fusion (GEN V)[10]. It concerns reactor safety revisions of Gen II reactors, pioneering work on fuel recycling (MOx) and fast reactor R&D in Mol. These activities are not new but ongoing developments since 30 years also in Belgium. They are evolving strategies interacting with resource use efficiency, environmental and waste issues and with proliferation and safety. Considering historic and strategic elements together allow not only to characterise crucial strengths and weaknesses of 50 y nuclear energy evolutions. The historical reframing can also contribute to prevent strategic errors in present and future (Belgian) policy commitments and goes to the core of what a pathway is, namely connecting a particular vision on a sustainable energy future with the current situation by establishing conditions for the eventual related development.
Comments on pathway elements are based on 12 years of environmental reporting work for VMM (MIRA 1996-2007) with the unusual and confronting application of the DPSIR methodology to the nuclear sector. The integration of a complex assembly of activities, emissions, and impact of all applications with ionising radiation encompassing energy has enriched the insight of the nuclear sector. The Technology Assessment (TA) usually done in the nuclear sector is characterised mainly by self-assessment with methods typical for the nuclear sector even for an environmental impact assessment (EIA).

IV.2 Clustered factor analysis shaping pathway elements

IV.2.A Reactor Technology I ☹ P 😐 S ☹ E ☹ G ☺

Nuclear energy for power production was launched industrially by President Eisenhower in 1957 after 10 years of military development for the atomic bomb.
Compact PWR technology was developed by Westinghouse and demonstrated for power production in submarines.
The PWR thermal neutron technology not only needs a natural uranium resource (0.7% U-235) but also fuel refinement by slight enrichment of this thermal neutron fissionable component to 3-4% U235.
Weapon grade uranium on the contrary requires a high enrichment to be efficient.

[10] Recent evolutions in Gen III and programmes for Gen IV development are presented in chapter III, IV and V.

A promising range of **energy technologies** through fission **opportunities** was opened up by R&D institutions financed worldwide.
In Belgium the Westinghouse technology was chosen in the start up of SCK. This centre was supported financially by the USA as compensation for the military delivery of uranium from the Congo colony. UK and France first opted for gas cooled carbon moderated reactors, creating less contamination problems.
A prototype PWR of 13 MWe (BR3) was built in Mol. With its dismantling in the nineties, it became a prototype again for dismantling technology of nuclear power reactors.
Industrial up-scaling of this PWR technology was constructed in Chooz by a French-Belgian consortium (SENA) on the banks of the river Meuse, situated close to the Belgian French meander border.
The upcoming French nuclear industry as well as later the British had to abandon their own carbon or gas-cooled technology in favour of the American water-cooled reactors. This first underground siting of a 300 MWe reactor was the embodiment of a *precautionary* approach regarding accidental safety. Chooz 1 was made operational in 1967. Such reactor siting became too expensive and too complicated later.
Chooz 1 had to be shut down earlier than planned in 1991 also for pollution reasons of tritium in river Meuse.

Other containment measures (instead of underground building) were chosen for the next generation of reactors aiming to reduce the potential impact of an accidental reactor melt. Russia meanwhile opted for less containment far away from population centres.

The Belgian utilities proposed in 1966 **investment plans** for 7 NPP’s to the government. A decision in principle favouring this proposal was taken the same year.
Their engineering companies progressively realised an improved **technology management** for those reactors of 390 to 950 MWe.
The Belgian safety in depth approach, based on double containment with multiple failure provisions was more expensive and safer than for new plants in France (ex. single containment on 6 reactors in Gravelines) and in the world. The aim was to allow siting near high-density population centres such as Antwerp where US siting criteria (10 miles for evacuation) could not be respected. The side effect of this approach was an optimised economic performance during decennia and a safe operational record (DPSIR study MIRA , VMM 1996-2007).

The reactor accidents with core melt down in Harrisburg (PWR 1979) and Chernobyl (1986) led to a revision of accident precautions with focus on human errors and management reliability. Melt down frequency had been underestimated by the MIT study, WASH-1400 for the NRC (Rasmussen,1975) due to the neglect of integration of the ‘human factor’ in safety engineering (Tanguy, 1994). Emergency planning was reorganised worldwide.
The social acceptance difficulties for siting new Gen II plants (Doel 5 project cancelled in 1988) were related to these accidents.
Under German influence new safety criteria (thermal inertia, core catcher) to make reactors inherently safe were integrated in new concepts of international consortia (Siemens-Areva) for the EPR, the European pressurised water reactor of the next generation (called Gen III. In fact it concerns an evolutionary concept of the Gen II PWR. Some technological aspects of Gen III are already applied in Belgian reactors for safety reasons regarding population density, but they cannot be called Gen III reactors as stated by Leclère (Suez) in the seminar on generation III reactors organised by SCK (SCK, 2010).

Meanwhile major reactor components of Gen II, such as steam generators (SG), suffered from corrosion, an underestimated problem. They could be replaced with growing success through complex work organisation ensuring low dose impact on the nuclear workers. This replacement resulted in an increased energy output (Doel 2, 433MWe; +10%) realised with low dose occupational exposure (ALARA) as a win/win situation. It enforced the strategy of plant life extension (PLEx). This approach is now the strategic core for ongoing decision-making processes opposing the phase-out decision.

Decision Making Processes (DMP) - from fait accompli to phase-out

The government had neglected to develop a full siting policy and failed in an adequate organisation of the State for the nuclear development in the second half of last century. Nuclear decision making was spread over 10 departments with poor coordination and weak administrations.
The order of 7 NPP's of increasing PWR capacity in 1966 was agreed by the government in one Council of Ministers session. It was approved easily without political debate and without any broader democratic involvement. There was almost no participation of other actors in decision making. The Control committee on electricity prices was contested that period and was not yet involved in assessing technology options. In later controversies this traditional kind of decision making in nuclear matters was called decision making by *fait accompli.*
Siting of these 7 reactors in Doel and Tihange interfered with the energy crisis of 1973. It lead to even more ambitious plans for the construction of 20 reactors. Siting had to be reconsidered. Further expansion met local opposition. Expert and media concern increased regarding reactor safety near city centres. Coastal or island siting became unacceptable for economic (tourism) and accident reasons. The turning point was the Harrisburg accident while Chernobyl consolidated this societal reflex.
A de facto construction stop of reactors is of application since 25 years and a phase out-law was voted by Belgian Parliament in 2003. It makes a shut down mandatory at the originally planned end of life cycle of Belgian reactors (40y reference scenario of NIRAS agreed with utilities). An exception is possible if supply is not guaranteed. Advisory committees even at the international level were set up by the government on this aspect arriving at controversial results (GEMIX, 2009). A principal decision was taken by the government to deviate from the law but the governmental crisis intervened and the decision could not be carried out as to date (December 2010). The discussion framework was not one of sustainability but of financial compensation by the French utility for a governmental budget deficit.
The decision making regarding phase out, discussed in IV.1, was characterised by a lack of consistency within and between governmental organisations. The Belgian Federal Planning Office applied the phase out law correctly in scenarios for 2050, noticing a need for higher electricity import in the period 2015-2025. Other institutions financed and controlled by the government have spent a limited part of their budget to support actions of nuclear industry intended to modify the law. As a law can be considered as a formalisation of value judgements in a democratic society in a given time span, this attitude, supported by leading (former) politicians is morally questionable. It was a source of controversy noticed and criticised formally by the author in the board of the Institute of Radio Elements (IRE).

Siting of old and new reactors is paradoxically no longer an aspect of decision making while crucial for accidental risk. This controversial frame of the seventies appears however at the horizon due to siting plans of much larger scale reactors (1700 MWe) at the Belgian borders.

Siting NPP(at borders) - Thermal pollution

Constraints regarding **site availability** became gradually visible in the past.
Underground siting was abandoned in favour of surface siting near major rivers at Doel and Tihange (1966-74). Some thermal pollution constraints were noticed after construction of the first Doel twin reactors cooled with river water. After assessment of thermal pollution (Commissie Beraad, 1976) the cooling towers became obligatory from the early eighties on.
As in France new siting at the sea coast was looked for but had to be abandoned due to well organised political actions. The controversy required more local involvement for siting.
The siting of Doel became controversial too, regarding the proximity of the city.
It was later noticed even in UNSCEAR that the particularity of densely populated areas has been overlooked in globally shaped assessment methodologies. This is made evident recently again by reconsidering dispersion of radioactivity in the densely populated areas of China.

Siting and its related uncertainties have dominated past controversies but receive almost no attention yet in present debates.

In Belgium, no siting opportunities exist any more except for one reactor in Doel on the banks of the river Schelde. The limiting factor for river siting is the thermal pollution capacity in summer conditions constrained by release limits in the river (Schelde) or by water flow restrictions (Maas). The thermal pollution and salt deposition by cooling towers, constraining in the seventies, was no longer considered at federal regulatory level in 2009. Thermal pollution is now a regional competence in Belgium. The non Radio Active (RA) pollution now receives minor attention from the regions.
Occasional summer cooling problems or demands for timely exceptional criteria due to reduced cooling capacity of the rivers occurred in Doel, Tihange & Chooz. Belgium has not required cooling towers at one of the largest nuclear sites in the world at our border, cooled with sea water of the Channel (6 NPP's at Gravelines).

Belgium is in the centre of the most dense network of nuclear reactors in the world with 100 of the 150 European NPP's in a circle of 1000 km around. Neighbouring countries have installed large NPP sites of PWR type near our borders (CEA,2009).
The **Graveline NPP's** (6X950MWe) without cooling towers have a lower safety level for accidents than required for Belgian plants (single containment). They are sited near the Belgian coastline with its prevailing S-W wind direction and its high population density in summer. The capacity of the site is equal to the whole Belgian nuclear capacity. Evacuation of the Belgian coast in case of accidents in summer could be very problematic, while iodine profylaxis is limited to the 30 km area and some stocks.
The nuclear electricity regional overcapacity created at Gravelines has attracted or extended energy intensive aluminium & steel polluting industry at the border in the Dunkerque port region.
In **Chooz** a new generation of 1500MWe NPP's was constructed in the period 84-96 at river level with considerable delay. A lack of coordination with France was noticed for releases and emergency organisation; this was contested by the Superior Health Council (HGR, 1996).
Considerable tritium pollution by early reactor fuel cladding technology occurred (large Tritium release in river Meuse till 1989 (24y)). It will create new exceptional environmental releases again during decommissioning in the future. The lifetime of this reactor was extended for another 10 years. Closure was necessary for environmental reasons while new technology developments were made available for fuel cladding. This illustrates a certain **relativity of plant life time**.
Projects of two other NPP's in Chooz (3&4) were abandoned after the Chjernobyl accident and due to environmental thermal constraints in river Meuse.

In future more high scale (1700 MWe) reactors (Gen III) are planned to be sited near Belgian borders (in the UK and at larger distance in Normandy, France).

The 4 Cattenom NPP's (1360 MWe) are sited at the French/Luxemburg border at the river Moezel with **thermal pollution** measurable till Belgium.
In Dungeness 2 NPP's (AGR's[11] of 545 MWe) exist near Dover.
The **Borsele** PWR (482 MWe) near Terneuzen is sited near the Dutch waste storage plant. It caused few concern in Belgium. Very recently a siting process started in Borsele. The utility Delta has set up a Strategic Environmental Assessemnt (SEA) process for siting new very large NPP('s) of Generation III (1700 or 2 X 1200MWe on the north river side of the Schelde).This causes concern in Belgian border communities. The thermal pollution could be measurable till Knokke, a select coastal village where siting of even smaller scale energy technologies (offshore windfarms) already turned out to be a sensitive public matter in the past.
Germany (17 reactors; 14 GWe PWR on 20.4) has about 10 operational reactors within 200 km of our eastern border. 29% of German electricity is of nuclear origin, but German utilities also produce 16% of electricity from renewables (2009). The German government has proposed early September 2010 to revise its phase-out policy by according 8 years more life time for the oldest and 14 y for the most recent NPP's (12y on average). As illustrated before the two periods of reactor construction differ in their level of defence in depth for preventing core melt down and resulting potential pollution. Nuclear energy and coal are however considered as transitory production capacities, as the German government aims for an 80% share of renewables for electricity production in 2050. The profits from a prolonged nuclear operation by EON, RWE, EnBW and Vattenfall are skimmed by a fuel tax amounting to 2.3 billion €/y with an obligation to invest in nuclear safety upgrading (0.5 billion€/NPP) as well as 15 billion € for renewables (numbers before ratification by the Bundesrat and subject of controversy). Public perception enquiries had indicated the importance of this conditional acceptance opportunity and the role of intra-generational redistribution.

UK has 13% nuclear electricity, Netherland 4% and France 76 %, compared to 54 % nuclear electricity in Belgium.

Electricity grid implications and problems

A black out of the European **electricity network** from Sweden to Italy occurred in 1982 due to a scram of a large Doel reactor. Nuclear incidents with grid failure illustrated the vulnerability of infrastucture in the 1970's and 80's, related to the large scale dimension of the nuclear power plants. It illustrates the importance of network equilibrium, both for its dependence on large-scale as well as small-scale (distributed) production units. This problem seems much more focussed recently on small scale power production because the grid organisation was shaped in Belgium for the large-scale nuclear input and interconnection with France.

Together with repeated corrosion problems on pressure vessels it illustrates that **the dimension of vulnerability**, usually only referred for resources (geographic) (low for U), **should be enlarged to risks related to technological complexity** in the context of sustainability.

[11] AGR Advanced Gas Cooled Reactor

NPP's are essentially dedicated for base load supply. But a limited load following became possible in France and later on in Belgium allowing more than base load production for NPP's. Load following was not considered as optimal from a safety point of view but authorised in Belgium by the regulator at stricter conditions than in France.
The French overcapacity in relation to base load fluctuations could be addressed by hydro pumping stations and net export (83TWh in 2007 or 75% of yearly exchanges, (Schnyder, 2009)) of electricity in the international distribution network.

Safety management - accidents - safety culture

After accidents with worldwide impact in the eighties, human and organisational factors were rediscovered as safety factors for reactor operation.
As a consequence **Safety culture** developed well in the utilities of NPP's in the nineties. It was accompanied by more adequate networking at NEA/OCDE level and in the World Association of Nuclear Operators (WANO).
Incidents in Fleurus, Mol and Dessel illustrated that a safety culture deficiency still exists in nuclear facilities where media pressure is lower and organisation reliability is less focussed. The communication of incidents to IAEA and the public, following an international classification system (INES; international nuclear event scale), was a considerable progress for feedback of experiences. It was implemented and recently generalised with management commitments by FANC for Belgium in a rather transparent way, with web access. The recent indication of an increase of low level incidents is related to the systematic application of it. It could also indicate a problem of maintenance deficiency (another near accident indicator), typical for some industries where international market competition becomes more prominent. On September 11, 2010, Le Nouvel Observateur noticed that 18 of the 58 French reactors (19.6 TWe of the 63.1 TWe) were not in operation due to maintenance compared to normally 4 to 5 reactors. France (relying on nuclear electricity for 76% of its electricity production with a large penetration of electrical heating) will thus require considerable import from November 2010 on. Maintenance had been delayed earlier for different reasons such as social friction due to increasing subcontracting within EdF. The availability of French nuclear production has fallen below 80%. Belgian nuclear plant availability has been better than 90 % with the best cumulative score for Tihange 1 at a certain moment as presented regularly by Nucl.Eng.Int.

The Roussely Report assessing the French nuclear industrial strategy made restructuring proposals to face the crisis on demand of president Sarkozy. This crisis is related to unsuccessful handling of Gen III projects abroad and in France by AREVA as discussed in V. It is proposed to give EdF a dominant position and a share of maximum 15% in AREVA for managing a second EPR project at Penly. Gen II reactor technology from outside France was considered for competition but seems opposite to French national nuclear industrial strategies.

Finally near-accidents of high importance related to corrosion problems on NPP's were reported internationally by WANO pointing out the continued need of surveillance and independent control on operating conditions of ageing complex structures.

Plant life extension

Plant life extension is a strategy of the last 20 years. It can be considered as a supervision of ageing (compared to health care). It is mostly characterised by decreasing performance and safety records. Replacement of major organic components such as all steam generators of

Belgian plants except at Doel 1 could improve the thermal output leading to an increased nuclear electricity production in Belgium in the last decennia – somewhat paradoxical in the context of an official phase-out strategy. Complex repair activities could be performed at growing efficiency. Meanwhile fuel regimes could be adapted based on decennial revision with improvement of safety components.
However, the core of a PWR NPP, the steel pressure vessel, cannot be replaced. It is a potential **major hazard** where containment could fail in accidental conditions. Due to its low probability it is not considered in the reference accidents, notwithstanding the potentially higher impact in particular for sites such as in Belgium.
This was presented at a workshop during a PISA seminar in Brussels in 2006, taking a critical look at the ExternE methodology for establishing the external costs of a potential nuclear accident. Pressure vessel rupture is dramatic anyway but environmental release could be delayed by double containment infrastructures of the most recent Belgian NPP's. It remains a major concern for large releases in case of failure as explained also to the Antwerp City Council by the author in 1979 and 1986.
Gen III reactor technology corrects for this by installing a core catcher, or sand bed for a melting core.
An RA contamination even of 1% of the extent caused by the Chernobyl accident could have dramatic impact on the Antwerp economy and traffic, even more so than the health effects. The latter are mainly considered in nuclear emergency planning, which improved a lot over the last 10 years. Major accident impact assessment and management is subject of a European R&D project (SARNETT)

The French nuclear electricity sector nowadays owns the Belgian NPP's. SUEZ has recently (2010) set up a strategy to prolong Gen II life time operation to 60 years or more (LTO[12]). Doel 1 – 392 MWe(15/2/1975) was recently refurbished with new steam generators, Tihange 1- 892 MWe (15/10/1975) - and Doel 2- 433 MWe (1/12/75) – are argued to have no technically defined life time and are in constant evolution due to the mandatory decennial review of design and operation. The law of 2003 puts forward de-activation 40 years after the mentioned industrial start dates. Royal Decree can allow a deviation in case of treat for the supply security. The utility argues referring to plant life extensions in the USA and the Netherlands and also refers for "Long Term Operation (LTO) to the definition of IAEA and WENRA safety criteria". The utility acts in accordance with a strategy note of the regulatory agency from 2009.

Qualitative Check of SD principles for PWR technology in Belgium

Integration (I)
As technological vulnerability related to the choice of a single technology (the PWR for 50% of a country's electricity production) was demonstrated to be real, this dimension should be integrated discussing energy dependence (I-).
The adequate institutional organisation of the State for authorising, controlling and managing nuclear activities, has to be guaranteed when making such long term complex energy choices. The deploy-ment of a regulatory capacity was delayed almost 20 to 40 years for the Belgian nuclear sector (I-).
Meanwhile the role of utilities and engineering companies shifted to a multi-national company level on which policy makers of small countries have little impact (I-).
The technological management of Electrabel itself was and is of high standard with priority for safety. Preventive measures in construction illustrate this and it was confirmed by assessments from IAEA in the last years (I+).
A main inherent weakness of nuclear power in Belgian society is the limited potential of reactor site availability in a densely populated area and in particular the sub-optimal site selection in the past near Antwerp (I-). This

[12] LTO: Long term operation of nuclear power plants by PLEx (new strategy of SUEZ-Electrabel-Tractebel)

context is what it is: a complex natural situation of a large city separated from the site by a large river where the prevailing wind direction is not allowing evacuation in a majority of circumstances. Moreover a complex structure of urban and industrial planning in one of Western Europe's logistic and mobility hubs has demonstrated its vulnerability, even in normal conditions.(I-).
A broadening of the emergency approach around Antwerp to socio economic considerations is relevant and necessary (I-) in order to consider this vulnerability.
The technological vulnerability of the economic system around such a suboptimal site has not yet been considered in the safety assessment for PWR neither for the present phase-out decision making.
Economic assessments such as organised by the EC only apply to average site conditions. No particular estimations are made at PSA level 3[13] for this site (I-).
The integration of the large scale reactor machines has also created problems from in the beginning when matched with small scale production facilities in the distribution network (I-). Grid integration, if approached in an objective way regarding technology options, should integrate this in due time. Decentralised renewables seem to meet similar concerns of smaller impact now.
Integration of environmental policy for nuclear energy decision making remains difficult at the regional as well as at the European policy level.
The ecosystem impact is marginalised by the use of an artificial dose indicator for health effects.
Precaution (P)
Early isolated precaution attempts existed within the nuclear sector. But military and security culture has overshadowed attempts for transparency (P-).
The neglect of human reliability and management reliability in reactor operation has shown a poor integration culture in the history of relative progressive safety in depth((P +)engineering approaches.
A low level of ethical respect for the law is noticed, related to a policy culture which has not yet created transparency in lobbying. Moreover a defensive expert culture confronted with group think strives for conformity and tends to neglect some safety considerations in periods of cholera (such as phase-out is perceived). Both characteristics have made it possible that governmental resources for research could be used to lobby for a change of the law.
The siting related history explains aspects of public perception. The (dis)regard of siting criteria now shows low prospective dynamics of policy makers (P-).
Thermal release in the atmosphere and river or sea of 2/3 of the energy output of large scale units is not negligible as a waste and pollution factor neither as landscape element (I, P-).
Stakeholder (S)
Almost no participative local involvement was planned (S-) in advance at reactor sites; the local community of Doel was eliminated for reasons of port extension.
Equity (E)
The technological performance and cost of Belgian reactors was excellent but distribution of benefits was doubtful (E+-). The real challenge of phase out decision making, the distribution of benefits received almost no attention (E-).
Global (G)
Reactor construction, operation and regulatory control became a global topic (G+). Rather positive global approach (G+) from the beginning but handicapped due to military strategies and lack of European harmonisation of safety (G-).

IV.2.B Nuclear fuel cycle I 😐 P ☹ S 😐 E ☹ G😐

The **fuel cycle** has numerous industrial phases: mining activities and tailing disposal, fuel transformation, -enrichment and -fabrication, electricity production, reprocessing, recycling and waste disposal. The efficiency of a single cycle of fuel utilisation in such a Gen II reactor type is however low (of the order of 1%) with considerable quantities of by-products of which some could be used in dedicated reactors for medical applications (such as iodine and molybdene-technetium).

[13] Probabilistic safety assessment at level 3 considers not only the chance of environmental releases(level 2) in accident conditions(level1) but also the site specific implications which could occur.

Belgium participated in an enrichment plant in the French Rhone valley. Iran was allowed in the past to join this project for a similar share as Belgium, a historical paradox difficult to digest to day in non-proliferation policy making.
The majority of by-products of this fuel cycle industry are not considered as waste but as potential fuel for later transition processes (basic idea of later Gen IV fuel cycles). Around uranium mines such as in Katanga, S-E Germany and France waste tailing piles accumulated. This creates long term environmental contamination problems (radium/radon which only became of concern much later; some even only recently (AREVA in France).

New fuel technology introduced on the present 7 reactors allowed till 1989 to reduce radioactive releases of tritium drastically except from Chooz 1 in the river Meuse. A residual release of tritium has been allowed by the Belgian government during dismantling in future. The improvement of fuel cladding, longer and more efficient reactor cycles with more enriched fuel allowed in the last decennia some optimisation of fuel at higher burn-up. This is increasing waste due to higher fission yield and has some non critical impact on risk for environmental release and waste as discussed by Volckaert on the Topical Day on Gen III (SCK, 2010).

A low resource-efficiency was not considered as a problem in the past. Recycling of spent fuel through reprocessing with abundant production of even more performant fissionable material –**plutonium(Pu)-** was put forward. Recycled Pu was first applied in atomic bombs, successfully developed in Belgium by Belgonucléaire for civil purposes. This was later opposed by American Democrats, such as von Hippel from Princeton (Ewing, 2009) and reconsidered for dismantling old missile fuel by American Republicans. Environmental, transport and proliferation concerns led to a decrease in popularity for this pathway element (Reprocessing and MOx) which became controversial in the eighties.

U resources

The estimation of uranium resources has had a positive evolution during the last years related to the expected expansion of nuclear investments. Increased market prices are allowing more mine exploration of low rich U content.
Mine exploration expenditures worldwide have doubled between 2007 and 2009. Total identified resources amount to 6.3 M ton U, an increase of 15%, including high cost categories of > 260 USD/kg U. Mining techniques had a move towards higher efficiency with reduced pollution and workers exposure over the last years (UNSCEAR report GE, 2010). The environmental impact of old mines is however far from negligible and tailing pile remediation has not necessarily been done in a sustainable way considering the long living radioactivity of the source term Ra. This will require additional expenses as is the case in France now. This will be important for Katanga in the future.
At 2008 rates of consumption of nuclear industry the total identified U sources are sufficient for over 100 years of supply. In the optimistic prospects of growth of nuclear capacity of IAEA (500 à 785 GWe in 2035), world U reserves are also projected to grow on historical base due to important discoveries or identification of new sources (NEA 2010). In the highest growth perspective less than half of the resources would be consumed in 2035. The challenge remains to develop mines in a timely and environmentally sustainable fashion as uranium demand increases.
We should also consider the time scale needed for new Gen IV fuel developments. Gen IV plans will slowly affect uranium market prices and will result in flexible market prospects within the coming century as they succeed. Deployment can positively affect long term

availability of U and could theoretically extend it to thousands of years since present resource use efficiency is only about 1% without recycling. A time scale of 100 years is however economically not so relevant within the complexity of innovation.

Industrial complexity

High **ambitions** were set historically to develop an almost **complete fuel cycle** activity in Belgium. The prototype reprocessing company of Eurochemic was the first civil plant in the world. International collaboration was successful but became an expensive adventure when facilities were taken over by Belgium due to omitted dismantling waste costs. Related R&D and industrial deployment was successful (MOx recycling in particular).
International alliances could take over major innovative developments of the Belgian fuel cycle industrial developments due to liberalisation, failing mechanisms of intellectual property protection, lack of political consensus on escalating costs and lack of industrial policy commitment. Most were taken up again in France by AREVA. AREVA is still directing these companies in Belgium (FBFC, Belgonucléaire in Dessel) in (preparation of) dismantling activities now. The local economy has suffered; employment had an international character but could be locally integrated to a large extent.

It was the aim to realise a Gen IV contribution *avant la lettre* in the context of a European collaboration, with the objective to breed fuel with fast neutron reactors in order to support exponential growth of reactor development. Costs, in charge of the government escalated and could not be continued on SCK budget in 1989. Safety and environmental concern on liquid sodium cooling technology did the rest. Up-scaling of technology in Germany (Kalkar) and France ((Super)Phenix) had been too fast. Belgium had developed fuel in Belgonucléaire and had committed expensive reactor tests in the BR2 reactor of SCK. Belgian Low Level Waste (LLW) from that period is characterised by a problematic high level alpha content due to these fuel cycle activities of the past. Disposal of this alpha bearing waste of fuel cycle industry requires adapted environmental protection criteria. It is discussed at present in the NIRAS waste plan where it could increase the HLW inventory estimates by 30%. FANC has only recently begun organising its competence for setting the authorisation criteria and for establishing the legal frame for nuclear waste management also related to distribution aspects of equity (insurances, funding).

Role of Nuclear R&D

Nuclear R&D received a huge public financing over almost 6 decennia with a maximum of 94M€/y in 1990. Public financing has decreased slightly in absolute terms the last twenty years, but remains very important compared to other energy R&D. A robust organisation with military culture and poor transparency evolved and dominated SCK policy till the late eighties. Restructuring was needed due to waste controversies and the Transnuklear waste scandal in the eighties. The nuclear research centre had diversified but non-nuclear activities and industrial tasks such as nuclear waste management (NWM) were finally split off in 89-91 with the creation of VITO and Belgoprocess, transferred respectively to the Flemish region and NIRAS, the Belgian governmental nuclear waste company created in 1981.
SCK continued afterwards with a reduced staff and a public financing at a level of 40M€/y, which would be kept constant over 2 decennia. The SCK budget has now increased considerably for financing long term fast neutron research (Gen IV). As nuclear waste and decommissioning costs had not been integrated in due time a social and technical liability support was needed, an order of magnitude higher in total than the yearly grants. This

financing was supplied by the government. Investments, supervised also by NIRAS were made slower than planned originally. Part of the waste which was only slightly radioactive could be given clearance at low cost. A number of dismantling and remediation activities still have to be executed. The application of the "**Polluter pays principle**" was however made mandatory in 1990 for new and ongoing projects, except at the IRE site in Fleurus, a regional spin-off of SCK in the south of Belgium.
SCK could survive crisis situations and political resistance over 15 years and succeeded in re-establishing its scientific international authority.
The IRE[14], was created starting from SCK activities for regional integration reasons in the sixties. It was successful in medical product development but could not become economically self-supporting. It was confronted with numerous crisis events. It attempted without success to take in charge a regional surface disposal task for the low level nuclear waste of NIRAS. A local partnership was set up (PALOFF[15]). But local policy makers opposed.
Regional compensation arguments were and are still used for waste costs at that site, where medical isotopes are produced by reprocessing high enriched uranium fuel irradiated in the high flux material test reactor BR2 in Mol. Policy compromises or regional compensations, characteristic for Belgian decision making for regional investments of federal competence, continue to exist at nuclear level between Mol and Fleurus and are not unimportant for present and future decision making on Gen III & IV.
After research reactor development of BR1 and Venus and construction of the BR2 (used for reactor loop and fuel testing) a prototype PWR was developed at SCK (BR3).
Probabilistic safety research of power reactors was left as competence to engineering offices and safety control institutes such as Tractebel and AVN.
The SCK had numerous research programmes mostly in EC programme context and in collaboration with the fuel industry and the utilities. They also offered support on safeguard investigations for the authorities responsible for proliferation control and had unique facilities for radio-ecological studies (farm, test grounds for contamination studies and radiobiological research facilities of world level of scientific authority.
Finally in the early 1980's an underground lab for nuclear waste disposal studies was set up. The assessment of the important socio economic impact was not considered as a research competence of SCK. It limited nuclear technology assessment. Only in 1999 integrated social research started on a limited scale in SCK Mol with the PISA[16] programme but within the programming economic research could never be developed as a priority for accompanying and guiding nuclear options.

Nuclear Waste Management

The neglect of nuclear waste management was put in the spotlight by the Assessment Committee for Nuclear Energy in 1976 (Com.Beraad, 1976), which required a solution for nuclear waste to be revised after 10 years as condition for further nuclear expansion in Belgium. The department head of Economic Affairs and chairman of the SCK board initiated a programme for geological field assessment (HADES) in SCK Mol. Belgium and SCK in particular were very proactive in creating such an underground lab (HADES) in deep clay layers (200 m. below surface). The underground laboratory remains a unique asset up to now for SCK in international waste disposal research.

TRANSNUKLEAR scandal in Mol

[14] IRE: Institute for radio-elements in Fleurus near ChareleroiT
[15] Paloff: Parténariat Locale Fleurus-Farciennes
[16] PISA : Programme of Integration of Social Aspects in Nuclear Research

Nuclear waste practices were not so clean in that pioneering period. **Waste** of low level activity could be dumped without control in small quantities on land in the sixties and in large quantities in the ocean in the seventies, even huge quantities of alpha bearing waste (Ra). This practise ended in 1984 after international controversy.
Later after the end of the cold war, generalised bad waste practices were detected in military sites in Russia and the USA even for HLW. Early disposal sites of low level waste (LLW) were not sustainable due to groundwater leaks (La Manche as discussed in NIRAS scientific board).
Technology for treatment of delicate organic waste was not available in Mol in an environmentally sound way till the eighties, contrary to official statements. It led to a crisis after a German nuclear waste transport incident near Mol, finally demonstrating corruption practices in waste handling.
NWM turned out to be very expensive in particular for safe long term management in deep geological layers.
Geological disposal of high level C waste from nuclear energy production has never been demonstrated in the world up to now except for military waste with minor heat generation in deep salt formations in New-Mexico, USA. But prospects are rather favourable in Nordic countries (Sweden and Finland), Switzerland and even in Belgium except on financial guarantees.
The late taking into account of long term **social responsibilities** (e.g. waste management criteria and financing, emergency planning) was symptomatic.
The organisation of the State for taking in charge liabilities from private actors for LT responsibilities of **long lived waste** became an issue and as the result NIRAS, the Belgian nuclear waste management organisation, was created in 1981 but became only fully operational in 1990, 24y after the decision-in-principle on series construction of PWR reactors (30 y including SCK reactors).
NIRAS is a public organisation controlled by the Minister of Economic Affairs and has also competencies for spent fuel waste management when operators have decided to consider this as waste. It had to take in charge the passiva including HL vitrified waste from former fuel cycle activities in Belgium (EUROCHEMIC), which had made no provisions for waste (as SCK). The last decennium NIRAS started to take over HL vitrified waste from utility operations without being allowed to organise full quality control of this waste returning from reprocessing by AREVA in La Hague.
NIRAS started to change its organisation culture at the end of the nineties. After late acceptance of the public refusal of sea dumping, it opposed public opinion by its siting policy of low level waste disposal and was forced by government to select an existing nuclear site. Participatory approaches were successfully developed in Mol and Dessel after complete refusal by a local public inquiry near Dinant. Finally the government selected the Dessel site for surface disposal of LLW.
Mid 2010 there was not yet a directive published on harmonising principles of RWM in Europe; a vague draft is in preparation.

The regulator FANC was challenged to develop regulatory criteria and a legal framework for waste disposal projects in Belgium. First proposals are in draft for consultation.
For surface disposal some local safety requirements for the construction (accessibility for control) had to be adapted regarding seismic as well as security considerations.
A future EIA however can still require reconsidering alternatives such as deep geological disposal for LLW, an excluded solution by the government for economic reasons.
The question of retrievability becomes an issue of societal concern brought up by broader public involvement also on HLW geological disposal.

NIRAS Waste Plan

In June 2010 NIRAS proposed its waste plan as a result of the governmental request of 2004 to prepare a societal dialogue for long term management of high and medium level waste (B&C). A related SEA (law 13/2/2006) was added. Different options and alternatives were discussed. The editorial process started in 2009 after unsuccessful public dialogues in the provinces. NIRAS organised an interdisciplinary conference in 2009 to look at needs and concerns of experts and industrial and societal actors. On our proposal (Bombaerts, 2008 updated and translated in Laes, 2009) NIRAS has charged an independent organisation, the King Baudouin Foundation to organise a public forum as representative reflector of public opinion. The results were taken into account in order to formulate the final plan of June 2010 (see discussions in SEPIA working paper of Hugé et al (2010) in annexe.
NIRAS asks for a decision in principle to continue developments in Belgian underground (slightly hardened) clay layers for definite disposal of this waste in a stepwise flexible DM process aiming for a sustainable societal support.
The new overpack design for HLW should prove its feasibility in future experiments and could guarantee enclosure for 10.000-100.000 years.
Boom clay is not exclusively selected but it is the preferred option, taking into account its plasticity and low permeability. It acts as a barrier, slowing down migration of radio-nuclides. With regard to depth and layer thickness Yperian clay layers perform better; these layers however have poorer and generally less well known, characteristics. Moreover 360 M€ has already been spent on the Boom clay research in Mol, offering interesting perspectives. Other site prospection will continue in north-east of Belgium. NIRAS will continue its research, in collaboration with SCK, to clarify remaining uncertainties. It is the aim to demonstrate robustness and to transfer a minimum of charges to later generations (precautionary approach) whilst leaving enough flexibility to decide differently in future.
Proliferation risk related to nuclear waste disposal should be investigated further following international indications.
NIRAS is framing its initiative within the sustainability context of the law of 5/5/1997. It proposes an integrated trans-disciplinary solution having 4 dimensions: a robust technology, a financial and economic framework, an environmental and safety dimension and a societal and ethical dimension. Sustainability is used as a guiding principle in the search for a balance between the 4 dimensions. Precaution and participation are taken into account while developing the *polluter pays* (and/or should pay) principle. NIRAS requires a refinement of the institutional framework to guarantee these equity concerns. Details are given in p 53-55 of the Plan and in MIRA 2007. (VMM, 2007 & NIRAS, 2010).
While low level waste will be disposed at the surface in a site in Dessel high-level cat .B waste will be stored in Dessel till 2046, and high-level cat. C waste till 2073. Heat delivering C waste needs cooling during 60 years or more. Closure of the clay facility is foreseen between 2085 and a further unspecified date early in the 22nd century.
An international solution is not considered as a realistic option by NIRAS. Storage for 100 to 300 y before deciding on disposal is rejected as well on the basis of precautionary reasons as for security reasons, maintenance cost and funding or payment uncertainty. The Netherlands on the contrary, having a smaller waste amount, have decided to reconsider disposal after 100y storage while opting for reprocessing contracts with France (with new recent flexible contracts, allowing waste exchange deals). This could also be argued on precautionary grounds but financial uncertainties are lower than in Belgium and the difference in time scope is relative as final disposal of high level waste will take on the average 100 y too (1960 first waste production till 2085 or later for disposal).

The NIRAS reference plan takes into account historical waste of R&D fuel cycle operations and waste from 40 years operation of the 7 reactors conform to the phase-out law.
Insolvability of an operator is considered as a real challenge. Non-negligible precedents recently occurred also in Belgium but outside the energy sector. In Zelzate f.i. a waste dump of phosphate waste containing radium enrichment had (Naturally Occurring Radioactive Waste (NORM)) to be taken in charge by the authorities due to a bankruptcy. It is being transferred for environmental risk reduction to a private company for a business related remediation operation.
For the first time too some transparency was given on Radium waste from uranium related operations in the past in UMICORE (before MHO) in Olen where for a majority of the low level long living nuclear waste a separate solution is looked for by NIRAS and OVAM.

Geological disposal could be required for residual waste from the nuclear energy sector originally intended for surface disposal. This could enlarge the needed capacity with 30%.

Uncertainties exist also regarding quality assurance of the waste, and availability of different funds in due time. R&D continuation should clarify these uncertainties.
The uncertainty related to phase out versus 10-20y PLEx of reactors and to the pathway element of reprocessing or not, is estimated. These factors could increase the needed capacity with about 50%. Utilities seem to wait for a change in governmental attitude towards reprocessing of spent fuel and do not decide in favour of an open fuel cycle yet. No time limit is set legally for companies to give spent fuel this final destination.
A clarification is needed in commitments and dismantling strategies of utilities as pointed out by NIRAS.
It should be noticed here that most dismantling waste will be cleared as non-nuclear waste with marginal residual radioactivity. This option of economic significance has not yet been made transparent to public opinion and could create opposition in future.

The public participation in the 2009 NIRAS exercise had pointed out the necessity of retrievability over 100 years. Regarding the definition of waste agreed by NIRAS and FANC retrievability is not considered. NIRAS gives a flexible interpretation in putting forward that retrievability will be de facto possible by the nature of the stepwise approach which can be corrected at any moment. The weakness is that costs for retrievability are not taken into account in price setting and funding. They will be considered in the parallel societal programme of the plan.

NIRAS is very clear regarding advanced nuclear technologies for Gen IV. They are no solutions as such for the long term management of B&C waste; there will always be a need for long-term waste management. The advanced Gen IV techniques are not applicable for the waste from the present Belgian reference programme. There is no need at all to wait for developments of these techniques. Moreover, NIRAS states that recycling feasibility is not demonstrated. This technique will apply at the international level (dimension not withdrawn by NIRAS, considering French a.o. legislative measures to refuse waste from abroad). P&T in Gen IV will need to be in operation over 100 years at least before reduction of radioactivity of waste will result while producing also long living high level waste.
This clear message is crossing political discourses on these Gen IV technologies. P&T creates an image of relevance at the horizon 2050 which is not realistic anyway. Potential results improving some aspects of the nuclear waste inventory will only show an effect at the end of the century. But it will require expensive programmes over a long time period. When these programmes should have to be paid by the utilities as waste producers more realistic market

corrections could apply. The polluter pays principle as intended and reconfirmed by the EC on the occasion of the proposal of a draft directive on nuclear waste management (EC,2011) was introduced in Mol after the Transnuklear Scandal but was not made mandatory in general due to compensation discussions between Belgian regions[17]neutron .
The new strategy developing specific fast n technology options (MYRRHA) and P&T **Fuel cycle transitions** will be discussed in the Gen IV chapter and will include a further reflection on **waste** implications. Some Gen IV options are presented as part of an intergenerational equity improvement for long term management at global level (Taebi, 2010),

Waste elements not taken into account (uranium waste)

The challenge of uranium waste from mining (tailing piles) and enrichment, considered as half of the waste problem of the whole nuclear fuel cycle by NEA in earlier studies (Baetslé, private communication) is not considered in Belgium yet as a major concern, except for Umicore, Olen.
The EC draft directive is not yet addressing this issue neither (EC,2010).
Due to the large potential volumes of waste involved this presents a problem also for many countries without nuclear energy production.
Contrary to statements of the Nuclear forum in recent (des)information campaigns, Uranium of low grade is stored in non sustainable conditions around mines and enrichment plants too. The latter problem can be considered as an important driver of fast reactor options where this depleted uranium waste was intended to be used as mantle for breeding.
Meanwhile indications exist on U and Ra pollution of the environment in former mine areas e.g. in Katanga.
Taebi (Taebi,2010) has not considered this inherent aspect of the uranium fuel cycle.

Qualitative Check of SD principles for nuclear fuel management

Integration (I)
Industrial integration of ambitious Belgian fuel cycle R&D was not successful in the past (I-).
Uranium resource efficiency is poor (I-) but resources remain abundant for at least one century of increasing Gen II or III operation, notwithstanding low thermodynamic energetic efficiency of present reactor systems (I+-).
Later dismantling challenges were not taken into account with adequate funding in due time (poor I- score).
Precaution (P)
Poor historic transparency (P-); environmental results were insufficient regarding waste scandals (P-) Waste disposal challenge in Belgium was considered rather early for the nuclear sector but started only 25 years after first waste production(P+). Precaution & equity distributive measures were not prospectively developed for waste (P-). But the new waste plan of NIRAS regards precaution, specifies uncertainties and balances value judgements. Retrievability could however challenge precaution (and S) in future.
Equity (E)
Distributive equity organisation (inter/intra generational and trans-boundary guarantees still fail at European level for waste but vague EU directives are in the pipeline of implementation. (low- E&P).
Rather weak equity result due to huge public/private transfer of responsibilities (nuclear passive)(E-).
Stakeholder involvement (S)
Robust State actors in research and waste were confronted with democratic challenges in a long crisis in the eighties (low- S, G)) but with considerable improvements the last 20 years.
Stakeholder participation came up mid nineties in research strategies for local acceptance of waste solutions(S+), but is not yet formalised in authorisation processes.

[17] *Wafle* policy making is a particular Belgian characteristic of a kind of communautary policy making. When two regions can find each other on different slightly related subjects to make a deal; they agree both to spend federal money for progressing each in their interest field. It was applied regularly in the past between the dominant political parties in the South (PS) and the Nord (CdV) for financing budget needs and seems to survive present new political relations or lack of them. A recent example in the nuclear field was the MYRRHA project of. SCK in the northern region with its huge investments while IRE in the south was allowed to reinvest for safety reasons together with new guarantees for isotope production facilities and related waste costs.

The recent NIRAS waste plan is a rather revolutionary approach for nuclear culture and the only approach framed within sustainability criteria up to now (Hugé, 2010). A rather high attention is given to integration (multidisciplinary, techno-economic social and ethical). Within the NIRAS waste plan, principles and mechanisms for the related equity dimensions were considered in a transparent and participative exercise while the initiative for assessment was delegated to an institute of high authority (the King Baudouin Foundation) with experiences in participative experiments, and having no links with the nuclear sector (independent)(high+ I,P,S). New controversies find their origin in the decoupling of the nuclear waste problem from new nuclear energy ambitions or phase-out, which should be reconsidered as an inherent condition for dialogue in the future.

Global approach (G)

A global impact on know-how was realised in fuel cycle industries with successes in MOx technology at world top level (G+).

The global dimension of NWM however remains weak; an international solution for free transfer of goods could not be given to an international problem decided in multinational companies (low -G).

The global smiley score reflects progress in waste management, neutralising historical mistakes, except until recently at the level of European Union where the original strong EURATOM instruments for fuel supply were not materialised.

The feasibility of waste disposal solutions for HLW should still be demonstrated and should guarantee trans-generational and trans-boundary financing in a framework of equity, not only at national level, but for the globalised liberal dimension chosen for electricity production in Europe (G-).

IV.2.C Drivers of development I ☺ P ☹ S ☹ E ☹ G ☺

Optimistic technology prospects

Technological **optimism** on fission energy production and the colonial uranium (U) resources have mainly driven the preparation and start up in 1952 of nuclear energy development in Belgium (BR1 research reactor in Mol).
Electricity growth perspectives were huge in the post war reindustrialisation.
Cheap electricity supply forecasts were based on abundance of fuel resources. The U resources in mines in our former Colony Congo (Zaire) were one of the richest in the world. No uranium ores of sufficient economic grade could be found in Belgium but an ambition for an almost complete industrial fuel cycle was elaborated. Commitments of the Belgian Crown and army and strong involvement of the multinational industrial interests around the Socièté Générale has dominated choices for nuclear energy in Belgium.

Civil prospects were marketed worldwide by the announcement of very cheap energy technology. Different technological dreams were not feasible or could never been demonstrated such as in organic liquid waste treatment. This lack of feasibility could only be made visible after the discovery of the Mol waste scandal in the eighties, pointing out the need for democratisation of robust research organisations.

Military Interests and Implications

The success of PWR technology was a consequence of **a phased upgrading of military prototypes** of this compact reactor core in US submarines to power plants.
As counterpart for Belgian U deliveries from Katanga for atomic bomb development, US financial compensations helped financing a national nuclear R&D organisation in Mol (see below) and supported the development of a prototype PWR Westinghouse NPP (BR3) for grid connection in Mol in close collaboration with utilities (training) and Belgian industry (delivery of components and engineering).
The military driven choice of pressurised water reactor type (PWR) for civil nuclear power plants (NPP's) (Gen II) did not result in the best technological choice from operational and environmental point of view. The UK and French gas cooled reactor systems and the advanced gas cooled reactor(AGR) developed at industrial scale in UK in particular, presented less environmental contamination problems than water cooled reactors and allowed continuous operation even during fuel discharge.
Access to US technology was conditioned by the signature of a non proliferation agreement with control at UN level (IAEA) and by obligatory State security control. The latter was established in Belgian law for sensitive nuclear activities of all involved staff members(1955).
The Cold War had accelerated atomic bomb atmospheric tests causing measurable world wide pollution. Controversy started supported by Nobel price winners, artists and intellectual networks worldwide.

Electricity Forecasts – Economic perspectives

In a period of industrial development driven by coordinated European Community efforts for coal and steel, energy growth was impressive, first supported by own coal resources for the heavy metal industry in the south, later by abundant cheap oil import and refineries and energy intensive petrochemical industry in the north.

The electricity sector, organised previously in a decentralised way was restructured in symbiosis with the related engineering groups to a performant and well-established national actor, firmly interwoven at local political level.
The Belgian electricity sector had started collaboration with French industry and constructed the first underground reactor of Chooz at a site on river Meuse encircled by Belgian territory (1967). 7 NPP's of increasing scale were ordered in 1966 for Belgium.
Utilities were stimulated by the growth perspectives of the electro-nuclear sector. They were scientifically legitimated by the nuclear research centre SCK. The staff of the utilities was trained on the prototype BR3 PWR reactor.
The forecasts presented to the government in 1975 predicted exponential growth (i.e. a doubling of electricity use in 7 years). This required a centralised production of high capacity, as potentially offered by the up-scaling of NPP's.
These scenarios lacked to consider energy efficiency and alternatives.

In this period the Club of Rome and leading universities in USA, UK and Denmark started to question the limits of growth, calling for alternative perspectives and starting reflexions on the present sustainability debate. It was symbolised those days by Schumacher's book "Small is beautiful".

Growing controversy forced policy makers to create ad hoc assessment committees of experts coordinated by SCK (Commissie Beraad Kernenergie). Its legitimacy was questioned in media for the conflict of interests of SCK in particular. Following publication of a substantive set of reports on economy, siting, safety, fuel cycle and environment, an assessment of societal feasibility was set on the agenda of the Council of Ministers.
This approach was driven by the common sense of a high-level administrator for economic policy, A. Bayens, who became chairman of the board of administrators of SCK.
The unrealistic growth perspectives and the siting acceptability were taken up as serious concerns. The conclusion of the expert report (*yes, but…*) for further nuclear development was proposed to become a (*no, except…*), imposing a series of conditions such as the development of nuclear waste management solutions, not yet taken into account. Electricity import was for the first time considered as necessary option to face exponential growth prospects. Siting constraints (also for touristic reasons) for large plants in a small dense populated country imposed limits on the growth of nuclear power and were set on the agenda by well organised action groups.

The growth prospects however had stimulated the **industrial deployment** of energy intensive industry also at the border sites such as the steel and aluminium industry in Dunkerque near the Gravelines border site where 6 reactors were built on the beach.
Moreover, the high penetration in the seventies (60% nuclear electricity in 1984; more than base load supply), lacked considerable hydro pumping capacity in Belgium, as was available for nuclear deployment in France and Sweden.
The medium term need for more capacity led to the construction in Chooz of 2 new reactors with Belgian participation in the eighties.
The lack of diversification and cogeneration became controversial.
The ultimate plan for an eighth Belgian reactor in Doel was abandoned after the Chernobyl accident. Most countries in the meantime had installed only a moderate fraction of electricity production capacity by nuclear power, less than a third of Belgium.
The resulting electricity "overcapacity" **hindered** the introduction of **renewables and REU** in the eighties. A depreciation of 20y for rather expensive plant costs, as made by Belgian

utilities, did not allow to produce nuclear electricity at reasonably low prices in a protected market and created a problem of intra-generational equity.
Due to **cost escalations** related to safety, nuclear reactor technology when reaching maturity is characterised by an incapacity to lower generating costs. This is contrary to most technology life cycles (IASA) where prices decrease when series production starts.
In September 2010 IAEA estimates that by 2050 12 % of global electricity could be produced by nuclear. IN 2008 372 GWe nuclear capacity accounted for 7.6 % of global electricity. 60 new NPP's are under construction world wide with dropping phase out planning.

Energy policy prospects at European level - EURATOM treaty

The European integration for coal, steel and agriculture extended to a new energetic perspective by the set up of a strong and progressive treaty (EURATOM), creating tools for policy implementation (Fuel supply agency, R&D, Investment support, Safeguard control) and creating a competence to harmonise regulation.
European member states (MS) who also had the atomic bomb however had started to organise their upcoming large national industrial entities interwoven with their military ambitions (Ex. CEA in Fr, UKAEA in the UK). It did not allow the EC during later decennia to fully develop its common industrial and regulatory tools (Vanden Abeele, 1982). Moreover the role of the EU parliament was limited from the early beginning by the EURATOM treaty and this is not yet reconsidered in recent years.
The EURATOM Treaty had given harmonising enforcing capacity to the EC for radiation protection regulation. A strict control capacity was set up for proliferation. It did not allow however to address the nuclear military developments of the 2 European atomic bomb nations (Fr & UK). The harmonisation of safety criteria remained of national competence with embryonic EU measures the last years. Nuclear waste management remained a national competence while waste production in small countries became controlled by multinational companies without European guarantees for financing the long term pollution costs coverage.
Globalisation was installed without setting up effective regulation at the global and even at the most relevant European level of globalisation, as proposed in general without success by the marginalised prospective EU research (R. Petrella, FAST).
After the oil crisis in 1973 the European Commission tried to set up a common energy policy to reduce oil dependence. The European electricity prognosis in 1973 for 2000 called for a huge nuclear growth. The capacity finally realised was less than half of the prospects.
No harmonisation and trans-boundary guarantees were set up for nuclear safety and waste management when electricity was liberalised in Europe.
Globalisation after the 2008 financial crisis, still misses a new framework of trans-boundary & trans-generational ethics.

Qualitative Check of SD principles related to historical drivers

Integration (I)
Three decennia of stagnation in investments was followed by a phase-out law (low I).
Revival of PLEX strategy for continued long term operation (I+) could turn out to be a successful strategy to neutralise political measures while even a small increase of nuclear production over the last 20 years could be realised.
New Innovative discourses are not yet evaluated on their bubble content. Lessons could be learned from financial innovations.
The dominance of external company interests attracted by the skilled level (social capacity) of the industrial tissue in Belgium could benefit in the past from a lack of property protection in research and innovation (low-I,S,E).
Integration was successful at operator level (I+);

The main utility at present in Belgium, Suez, has considerable international ambitions for which the successful Belgian nuclear (engineering) sector is a core activity.
Integration became insufficiently realised for society regarding complexity of risk management and the lack of assuming inherent regional & local responsibilities (I,G-).
Finally the high share of nuclear in electricity production capacity kept total energy efficiency low (I-) e.g. by delaying cogeneration.
Precaution (P)
On this aspect of primary importance for sustainability, the robust nuclear sector is delayed due to a limited capacity to develop a prospective worldview. There was few environmental preoccupation of life cycle impact (low P-). The perception on environmental impact was negatively influenced by military developments and could not be integrated in the EURATOM competence (I-). Nuclear culture was determined by military culture of secrecy hampering the structured integration of transparency (P-).
Suez's production capacity when including its USA ambitions has one of the highest carbon emission scores of all utilities in the world (P-) which explains its recent turn in favour of renewables and the strategic importance of the Belgian nuclear production capacity in its portfolio.
Equity (E)
Environmental costs of cold war were huge (E-,G-) especially in the former Soviet Union but also in and around military research centres in the USA, illustrating the importance of transparency and trans-generational transfers of social costs.
Market prices masked the potential distribution of the benefits of the nuclear energy production at low cost after 20 years (E-)
Stakeholder Involvement (S)
Historical policy "du fait accompli" was changed for reasons of public opposition (to waste solutions) into participative experiments. Near future will shown if participative democracy will also be introduced for new long term fuel cycle and fast neutron reactor options, where decision making with large financial and industrial implications, is ongoing in Belgium
The lack of democratic clarity of safety criteria and their implementation up to recently (S-) was a major argument for on going proposals driven by WENRA for change of the Belgian safety regulation
Global approach (G)
A global outlook with integration framework and perspectives was made available in due time at relevant EU level but could not be deployed as effectively as European founders aimed (G+,+/-).
Globalisation of electricity was organised while a common good actor (economic regulator) at national level lost its full capacity to intervene (I-).

IV.2.D Nuclear technology Regulation I ☹ P ☺ S ☹ E 😐 G 😐

Health and Environmental concern

After clear epidemiological evidence of leukaemia effects in Hiroshjima in the fifties followed by evidence for other cancer effects, regulations were set up for the application of ionising radiation. As required by EC this was implemented in Belgium in the sixties in order to manage risks at nuclear facilities.
The risk of low dose became an element of controversy while nuclear industry succeeded best in organising good operational practise at NPP's. Controversy was taken over by the medical sector where exposure raised considerably with a growing number of incidents.
Finally international peer review (UNSCEAR) confirmed that a precautionary approach (ALARA) was needed with evidence growing on cancer risk but also of other degenerative diseases and underestimation of risk for cataract due to ionising radiation. Genetic susceptibility calls for a distributive justice discussion on exposure detriment, which should be justified in the context of an optimised protection.
The set up of competent authorities to authorise and control nuclear energy was however neglected. The State was not organised to face the challenges over 30 years. Crisis situations with policy contradictions were amplified by media and finally led to a crisis of the regulatory

system and nuclear acceptance in public opinion. The nuclear regulatory agency was structured effectively only in the last couple of years. Now the yearly reporting on nuclear safety, made mandatory by the IAEA Joint convention on Nuclear Safety creates a picture of the real progress made (FANC, 2010) and of the large efforts and results the sector has made in establishing safety culture and numerous efforts to improve safety of ageing plants assessed by OSART missions of IAEA experts in Doel 1 & 2 and Tihange 1, with follow-up of remediation actions.

Environmental approaches and accident management

Release criteria were respected in general by nuclear plant utilities in Belgium. Released quantities in normal operation are low as indicated by the MIRA indicator follow-up of VMM.
Environmental releases are scrutinised rigorously and communicated to FANC.

There were however difficulties in the development of a public network to measure RA in **the environment** (atmosphere and rivers) by FANC (Telerad), in order to be prepared to **emergencies. This system was criticised a lot during** the last 20 years of development. The delayed response capacity in crisis situations (imission overview as base of risk estimation) was identified as a major problem but progressed and is now subject of reinvestment after difficulties in interpretation of incidental releases by IRE Fleurus in 2008 (FANC website and FANC, 2100). A lack of transparency still exists on emission values at nuclear facilities. The regulator is hesitating on full emission control in NPP's for liability reasons in case of emergency.

The measurements of RA pollution in the sea at our coast were reduced due to other priorities in SCK. Transparency on river pollution for RA of tritium is also incomplete. Tritium of low radio-toxicity could require more precaution in future due to environmental impact uncertainty and planned releases such as in Chooz. The water quality of river Meuse can have an impact on the water supply of Antwerp (AWW - Channel Albert).

Poor **coordination of environmental measures** by countries in the past is intended to be prevented by enforced data gathering at UN level (UNSCEAR) which is far from complete. The new EU SEA approach and new regulatory tools such as the OSPAR (OSPAR, 2010) and Aarhus conventions are aiding significantly.
OSPAR was contested by the nuclear sector for using direct impact indicators instead if indirect indicators (dose). The quantity for radioactivity could yield more transparency regarding major environmental releases which still have uncertain consequences, such as for tritium. The Aarhus convention is still challenging the organisation of transparency within nuclear culture.
EURATOM instruments to manage trans-boundary pollution, such as the art. 37 group are however not yet integrated in SEA processes and only act during the final authorisation process.

Most Radio Active (RA) noble gases in reactors and fuel cycles, such as xenon and krypton are released to the atmosphere without having a major dose (health risk) impact. This is in principle comparable to what happens with CO_2 release in carbon fuel cycles but with much less plausible risk.
Only a ecological system approach for compartments, such as the atmosphere, could enlarge the human dose related anthropocentric approach of radiation protection. Currently potential

atmospheric effects of ionising radiation (ionisation of air in atmospheric layers, atmospheric electricity) are not taken into account and almost not studied anymore. Nuclear risk assessment approaches only consider direct effects on humans such as the potential increase in skin cancer risk due to atmospheric release of radioactive noble gases. This is considered as marginal for radioactive exposure alone.

Some concern is growing on epidemiological significant unexplained leukaemia clusters in children around NPP's in Germany and UK. This scientific uncertainty and ambiguity could have an influence on future siting. For radioactive short-lived noble gases measures were not always stringent as best available technology allows. Short lived noble gases can be held up and stored for decay, what now happens most of the time in Belgian NPP's but not yet during reprocessing for medical isotope production in Fleurus (Braeckels, 2010). This problem of environmental association of childhood leukaemia is being evaluated by the Belgian Health Council in a European project (EUSANH).

Authorisation processes - Safety & Radiation protection control

The regulatory capacity in the past was dispersed over different ministries and had a very limited capacity to be able to authorise installations and to control them. The important operators had a large influence on safety criteria inspired by US regulatory guidance and on environmental release approaches. Most activities regarding evaluation of safety and field control or supervision were delegated by the authorities to private organisations of high level individuals. They had potential conflicts of interest with the involved nuclear actors (such as CORAPRO with SCK).

Structurally the regulator was not adequately organised to face crisis situations. The chance of an accident with large impact was not considered realistic by the dominant engineering culture of that period till a core melt accident happened on a PWR (1979). A lack of preparedness of the authorities in crisis situations was demonstrated during the accident of Chernobyl.

The intense development of nuclear technology and services in Belgium however allowed to organise expertise, yet not in a coherent way to face media communication. The accident in Harrisburg and the growing media attention had first of all contributed to improve the safety organisation and safety culture of the utilities.

The Chernobyl crisis clearly illustrated that the State as regulator was only organised in Belgium for setting up some regulations requested at the international level and for organising authorisation processes but not as a guardian of the common good. This became evident in accident crises during the Transnuklear waste scandal in SCK.

Deficiencies in the (safety) organisation of operators were also clearly demonstrated during the waste crisis in SCK-CEN between 1986 and 1991 where military culture originally had dominated. This deficiency was corrected in Mol in the nineties but has cost a lot to remediate. Recently, it re-surfaced in IRE.

Final waste management was decoupled from nuclear operators in 1991 essentially launching NIRAS. Measures were taken in Belgium to restructure all aspects of the regulatory authority.

A **nuclear regulatory agency,** FANC, was created in 1994 after 15 years evaluation of dispersed competencies of the authorities.

But the agency could only be structured in an effective way in 2004 after another crisis, mainly due to industrial disagreement with political restructuring. Parliamentary inquiry had analysed these accidents and crisis events and came to clear options regarding independence. After a long political impasse a new management directed by a former utility manager could integrate a major private control organism and increase independency, The capacity was increased with more intervention opportunities in the field as well in the medical, research as the industrial sector. The control institution of the highest risk class 1 was integrated in 2008 in the Agency FANC (BELV). The advisory scientific board with mandatory competence in decision making on nuclear safety could continue to function.

An adequate organisation is now functional at governmental level in 2 institutions: NIRAS, for nuclear waste management and FANC for safety and radiation protection regulation and control.
A future evaluation could demonstrate within some years the final success of the new FANC approach. A critical study of this recent particular history is (Vanmarcke B., 2009). It recommends in an idealistic manner to depoliticise the board and management committee of the agency FANC through a vertical hierarchic control from the central government in order to break down dominance of the sector. Political feasibility of such option is uncertain since the political grip on the shaping and independency of the regulator is growing again in the context of the political crisis, focussing the CEO change mid 2011. Similar indications were noticed abroad. In Canada the CEO of the regulator was fired after DM on a reactor stop and in France where the CEO of EdF questioned the independency in principle of the regulator (ASN) (see Gen III discussion).

The reconsideration of nuclear safety as priority for the nuclear utility in Belgium is however impressive and projected or legitimated with more authority since FANC fully assumes the final responsibility of safety reporting at IAEA level (Joint Convention).
At European level, collaboration of regulatory authorities is growing through the activities of WENRA, the West European nuclear regulatory association and HERCA, the organisation of Heads of European Radiation Control Authorities and through the creation at EU level of a regulatory advisory group (ENSREG) (www.ensreg.eu).
Since the EURATOM Treaty did not address nuclear safety explicitly, there was no legal base for any harmonisation of safety criteria before the directive was published in 2009. The competence remains national but a commitment was made to respect basic principles and to improve transparency. FANC started a process and consultations to implement this in Belgium. The directive 2009/71/EURATOM fixing a common EU frame for nuclear safety of nuclear installations however remained vague and is not giving a more important role to EC in watching local decision making.

Regulatory phase out management

The influence of the sector was again demonstrated in 2010. Paradoxically, the regulatory agency took more measures to prepare a future without phase-out than preparing phase-out consequences or alternatives. In the frame of decennial regulatory safety revisions, since 2009, the regulatory agency is working out a plant life extension strategy for the Belgian NPP's from 2015 on, assuming a withdrawal or unilateral interpretation outside its competence of the law. FANC is not presenting an equal state of preparedness in case the law persists. This attitude could be considered to be partisan.
The strategy text evaluates preconditions of Life Time Operation (LTO) (dependent on policy decisions on phase out) and opens discussion on ageing management and design upgrade to be submitted in 2015 for execution before 2020. The required regulatory framework with a step by step planning is worked out. It is noticed that a balanced approach of other base line references is not developed: no comparison is made on safety with a real phase out (the law) or with an alternative transition project (Dutch scenario) of the third generation. It is noticed

that the same utility competes elsewhere (UK, FR,…) for Gen III projects with improved reactor design which is also safer (e.g. core catcher for pressure vessel rupture) for siting in densely populated areas such as Antwerp.
These options could be compared also in search of the most sustainable solution from a precautionary point of view. The time scale put forward by the utilities is beyond 2045 (60 years LTO for the other 4 reactors), the SEPIA timing for a sustainable energy future. Justification is a legal requirement of Belgian royal decree (ARBIS, 2001). This should include however all relevant societal aspects and not only nuclear safety. It has been noticed that the nuclear regulatory agency FANC has progressed in independent specification of safety and environmental criteria, preparing its regulatory framework for this LTO plan and not yet for the decommissioning of the three out-phased reactors as put forward by the law at present for 2015. FANC has never considered up to now sustainability assessment or safety comparisons with alternative options such as new nuclear plants, as proposed by the Netherlands recently on River Schelde, some tens of km downstream.

European Context

The Belgian scale does however not allow to fully master the nuclear complexity at national level in particular regarding future challenges of generation III an IV and fuel management projects. This will require a more effective approach at European level.
Due to the preference of member states to keep a large national autonomy in nuclear decision making and due to the particularity of member states such as France with its industrial ambitions and UK,both having an atomic bomb capacity, the European role is kept at low level, in particular regarding implementation of nuclear safety and waste policies. A better integration of the EURATOM treaty in other European energy and environmental policies could be realised forced only in the long run through enforcement of the role of the European Parliament (EP), with attention for sustainability principles and policy coherence.

Some attempts were made in the beginning of this century to improve EU effectiveness on regulation and harmonisation of nuclear safety and waste policies in Europe, but EC lost grip on harmonising regulatory criteria and implementation with the entry of the new member states. Bilateral collaboration of governmental institutions then took the lead. At the industry level resistance against stronger governmental impact on nuclear control has strengthened, international networks are legitimated more by self regulation than by democratic control. The last 3 years it could be noticed however that EC, NEA and IAEA started to focus on crucial elements of incoherence in nuclear policy regulation such as the lack of harmonisation on reactor safety, lack of regional waste approaches, liability coverage and incident reporting. This resulted in new but rather vague policy instruments for reactor safety and waste management, introducing the idea of international conditions.
Poor democratic control of complexity at international level seems slightly balanced by progress in practise as illustrated by the report on nuclear safety (FANC, 2010).

Transport of nuclear materials and waste in dense populated areas became a particular constraint for waste transfer and for siting or enlarging capacity of nuclear fuel cycle industry (MOx, HL nuclear waste). The negative perception was fed by a series of accidents (such as Montlouis in 1984) in front of the Belgian coast where national competencies failed to solve the problem. Transport criteria are globally developed under IAEA umbrella and a directory was set up at EU level in 2009 however paradoxically separated from RP regulatory authority. The diversity of national regulatory practices in Europe remains a major handicap.

Proliferation control

The IAEA non proliferation treaty is successful in its end result up to now. It was one of the first proactive tools on global risk governance. There was no effective misuse of fissile material since. It focussed too much on fuel and was proved to be insufficient for technological risks.
The link between civil reactor technology for low enriched uranium and atomic bombs was denied over a long period even by Synatom.
Belgium continues to use highly enriched uranium for a research reactor and for medical isotope production which should be abandoned following US criteria for > 20% U-235.

Attitudes of governments were not always consistent. The contradiction between the '*haves*' and '*have not's',* is questioning final success.
More efforts could be made for the ultimate goal of dismantling of all nuclear bombs.
Proliferation risks were underestimated in the past (Irak) and not always treated consistently (Cornelis, 2006). The USA had to bomb U fuel cycle installations of Belgian origin in Irak in 1991. These U recuperation installations were delivered by Belgian industry and engineering companies with support of the Belgian Ministry of Economic Affairs.

There remains a resistance against the additional protocol within the Non Proliferation Treaty (NPT) which could allow to address more the whole technological process and steps towards acquiring an atomic bomb. Historical evidence has shown that there is no assurance to detect proliferative activities without this protocol. New measures are even necessary. Some countries continue to refuse it, or do not support it, such as Brazil. The position of Israel and Iran is dubious and Pakistan blocks some initiatives.
A nuclear test free zone in the Middle East could be a first step towards a nuclear weapon free zone in the Middle East.
But also the efforts of Russia and USA to dismantle warheads and recycle Pu for civil use should continue while giving the competence to IAEA for verification of Pu disposal facilities.
It is now the aim to reach new international agreement at a NP conference in 2015.
Nuclear industry and nuclear research could support with more efforts the regime of NP.

National responsibilities were also reframed in the terrorism policy area in the wake of controversies on know-how transfer to e.g. Pakistan and Israel.

Proliferation risk and even nuclear material abuse could have considerable impact on public perception in future. Non-proliferation should no longer been considered as an Utopia. (Goldsmith, 2010)
Regarding the historic responsibility of Belgium for delivering bomb resources, the **major ethical challenge for nuclear sustainability, proliferation**, could be put higher at the agenda for its potential destructive global power (G).

Liability – Insurances

International agreements (Paris convention 1960 and Vienna 1963) offer global instruments to manage third party liability. Regardless of fault, the operator is liable through mandatory insurance controlled in authorisations but with limitation in amounts and in time. The polluter pays principle and the "restitution in integram" legal principles should apply. But for catastrophic risk of low probability and high impact a gap exists between what should and could be done. The new Paris convention of 2004 was reconsidered regarding Chernobyl experience. The objective was offering more financial compensation to more people for a wider range of nuclear damages. Coverages up to 700 M€ are set for the operator, 1.2 billion € for the national government and 1.5 billion € for EU (3B € in USA). However, in most countries such as Belgium, national coverage is still at 300 M €. Nuclear user pools determine the amounts. For Belgium the insurance pool Syban is setting the minimum level. A European harmonisation is still lacking. The crucial question for sustainability remains if nuclear risk can be insured properly and should be continued to be seen as a moral hazard.

For dismantling and waste financial resources and funding are the issue for very long term effects and eventual remediation actions. They should be available but are not yet legally guaranteed by companies at international level. The joint convention (IAEA frame) on safety of spent fuel specifies the responsibility of the licence holder and if not or no longer existing the contracting party. But this remains relative at the very long time span for nuclear waste issues and continues to challenge sustainability.

The extent of risk coverage regarding long term effects (cancer and environmental harm) is not fully taken into account and is still limited to 10 years. National and international States should take into account a high coverage regarding potential impacts of contamination in large territories, in particular in dense populated areas.
A pool of the nuclear utilities could take this fully in charge at the European scale level where they are operating since liberalisation of electricity markets. The so called nuclear package directive however failed at that level and was replaced by vague specifications for safety and waste not covering the whole societal challenge of nuclear industry.
However the legal liability basis is more elaborated than for non-nuclear risks where the intervention of insurance companies is less guaranteed.

Qualitative Check of SD principles related to Nuclear Regulation

Integration (I)
Up to 40 years after decision making in Belgium over one of the most ambitious nuclear parks in the world (1966) no independent public body was effectively organised as regulator during 30 years, neither for waste management (I-).
The nuclear regulatory agency became operational in the last decennium; coordination of regulation of waste management is very recently in the pipeline (I+).
A PSA level 3 study for the particular Belgian sites of Doel and Tihange could be required as P and I based rational measure before changing decision making on phase out, which essentially is an intra-generational distributive issue (I-).
Precaution (P)
Environmental concern was existing (P+) but integration was poor and is still based on the anthropocentric approach that mankind is enough protected if man is (low I-). Radiation is only one among the stress factors for man and the environment, still given an isolated attention regarding health impact. The influence of new environmental ecosystem concepts has redirected some nuclear options (stop on sea dumping of waste; obligation to consider alternatives in EIA (low P-, I-).
The positive health effect score of nuclear energy and the releases with limited impact during normal operation illustrate however early attention for important aspects of precaution (P+)
Integration of health and environmental precaution is improving, but not so much at international level of standard setting where precaution is still questionable regarding value judgements on genetic susceptibility (ICRP). Also for clearance, perception is not yet anticipated for economic reasons.
Sustainability is almost not discussed in nuclear except for exogenous factors such as climate; in this regard, paradoxically, an ecosystem approach is usually strongly referred for the atmosphere by the nuclear sector. This contrasts with the anthropocentric environmental approach in the nuclear sector itself which is not considering atmospheric burden (P-).
Environmental and health risk communication requires a framework for objectivity not yet respected by nuclear operators (such as proposed on a scientific basis by the RISCOM model). Transparency discourses are organised without guardians of the process, except in NIRAS experiments of participative democracy (P-).

Equity (E)
Regulatory strength and lack of State preparedness for accidents has improved through bilateral collaboration but the liability is not fully covered neither in accident conditions neither for waste (P+,E-)
International preparedness still meets borders: stable Iodine distribution for profylaxis is not yet operational in pharmacies at the Belgian sea cost, notwithstanding the prevailing wind direction along the Belgian coast. The largest nuclear park in the world sited at Gravelines at 30 km from Belgian sea resorts could hurt 1M people on the 60km coast line in summer, with limited perspectives for efficient evacuation (E-).
An intra- and inter-generational distribution problem continues to exist due to a non taking into account of long term cancer effects in insurances; this shows incoherency with low risk discourses.
Regulatory progress and improved networking is clearly aimed for at international and national level (insurances). The WENRA pressure on improvement of national regulations is real but the EC has few implementation competences.
Stakeholder Involvement (S)
Communication initiatives of utilities do have a influence on the functioning of the regulator supervised by the government. The new Electrabel strategy of Long Term Operation of NPP's beyond phase-out (post 2015) has been facilitated by a strategic document of the agency (FANC). FANC is not preparing on a neutral base the different possible options (phase-out elimination, modified partial phase-out or application of the law).
The new subtle marketing strategy of the Nuclear Forum has not integrated structurally conditions for transparency. The "hidden" agenda was the phase out interest. European modelling through research for good communication (RISCOM model; see Anderson, 2008)) requires that those processes should be directed by an independent guardian and stretcher in order to be effective for creating transparency (truth, authenticity and legitimacy) (S-).
Global Approach (G)
Notwithstanding the regulatory progress at international level (G+) the continuous threats for proliferation are the major challenge for sustainability (G-)

IV.2.E Social Interaction: I ☹ P ☹ S 😐 E ☹ G ☹

Risk communication - Public perception and transparency

In recent years, NIRAS and FANC took up their mandate of public information and communication put forward by their legal framework. Information became much more professional and accompanied by communication officers. Web access now allows the public to follow actual events in a direct and open way (FANC) forcing operators to act more than before due to media pressure.
Nuclear research centres like SCK with its PISA programme contributed to study communication mechanisms and perception (Perko, 2010). Professional organisations like BVS contributed to discuss progress. The superior health council essentially stimulated information at policy level for the use of radiation in medicine and occasionally for environmental issues.
Action groups like Greenpeace with a professional international strategic communication approach could no longer direct the societal debate through strategic information campaigns as the decennia before. Compared to State research Institutions aligned with nuclear industry, these action groups, have a very limited capacity to play a role in the assessment of nuclear complexity. The new "pragmatic" young generation seems also less attracted by traditional messages focussing on risk perception.
Media continues to polarise controversies amplifying simple contradictions and incoherencies between safety discourses and (risk) management.
Investigation journalism however is disappearing, notwithstanding important historical reconstructions on Belgian public television (Canvas).

The Belgian nuclear forum, a powerful organisation of the nuclear industry launched a subtle campaign[18] directed by Saachi & Saatchi, in order to neutralise phase-out law and nuclear criticism. This contributed to the action groups' refusal to participate in public fora on waste due to collaboration in the campaign of Belgoprocess (BP), the industrial daughter company of NIRAS.
It remains an open question whether implicit information censoring occurred during these promotion campaigns addressing press headquarters massively. They had considerable funding even from governmental research institutions and from French nuclear industry. The action was considered as a success for its originality by nuclear industry; FANC and NIRAS refused to contribute, but BP and IRE, both audited in recent years on their safety culture, have supported the Nuclear Forum campaign.
The information completeness however lacked, as was noted in the marginal representation of the nuclear waste subject where fuel cycle waste outside the country (U) was omitted, conflicting with the principle of life cycle analysis.
The campaign paradoxically activated public debates and could have a boomerang effect in the long run on dormant nuclear action groups, but they were missing capacity to face the extent of the campaign.
The campaign was not respecting EC research results or conditions put forward on how to realise transparency which could create contradiction again on this major challenge of nuclear sector in the past. It was noticed that emotions were not only a characteristic of laymen. The driving of group-think effect can decrease rationality as a general problem, in particular for experts (PISA/SCK research indicator, (Bombaerts, 2006).
New governance initiative trying to organise public involvement are already manipulated by organisations having interest in the subject at both sides. So networks of the nuclear industry, such as the (Belgian) nuclear society, mobilised its expert members in reaction on Greenpeace call for public reactions on the public involvement initiatives regarding the NIRAS waste plan, by arguing that a 'solution' on the waste management issue would contribute significantly to the perceived legitimacy of continuing nuclear power production in Belgium. Greenpeace on the contrary does not accept decoupling of nuclear waste policies from options in nuclear energy.

The US Westinghouse company representative suggested ENS at the Barcelona meeting publicly in 2010 to address proactively the *re-galvanised* anti nuclear groups by using a more aggressive communication focussing on the supposedly green affordable and safe nature of nuclear energy.

[18] www.nucleairforum.be

Public Perception

At three times between 2002 & 2009 SCK has organised risk barometer inquiries amongst the Belgian public parallel with the EURObarometer of EC. There seems, contrary to the assumption of the Belgian Nuclear Forum, no general fear for nuclear activities *(PISA 2010)*; the perception of nuclear and chemical waste and nuclear terrorism decreased; people become slightly more conscious of natural and medical radiation risk. Low confidence in authorities improved over the time span and is related to their presence in the media; people feel better protected; people however believe that authorities understate environmental releases when communicating. There is lack of confidence on correct info on nuclear accidents and waste ; people trust media more; nuclear emergency preparedness like iodine profylaxis was welcomed and meanwhile proven effective contrary to earlier expert perception before Chernobyl. People are not willing to spend much time in participation experiments. There is a more positive attitude towards nuclear energy than in 2002 but still half of the population approve a reduction of NPP's in Europe: only 6% strongly agrees and another 6% strongly disagrees with nuclear energy

Perception is defined as an impression of reality.
Good information has an important impact where experts are requested to verify the truth of statements. It has been noticed however that legitimacy (are we doing the right things?) as well as authenticity (no hidden agenda) play a role in risk communication, perception and confidence.
It is the **core difficulty of transparency** (a sustainability element) for the nuclear sector. The improvement of rational information of risk is insufficient; outrage of people could be as important and is determined by historical experience and coherence. In order to be successful outrage management is as important as good unidirectional information following Sandman[19]
Conditions for implementing transparency in risk communication are represented in The RISCOM model and discussed by us (Laes, 2009, Anderson, 2008). It was co-developed and validated by PISA/SCK but paradoxically not applied on the working of the Nuclear Forum (itself supported by SCK).

Safety at work

The work related doses received in the nuclear energy sector had a very good evolution as well for individual maxima as for collective dose indicators. This essentially refers to complex interventions like steam generator replacement and fuel charging at NPP's. Incidents have increased but they are of limited nature and could be related to the improvement of registration systems and due to more open communication for feedback of experience. Nuclear safety culture is much more established in NPP's than in other nuclear institutions and medicine.
A particular exposed population is not receiving prior attention for follow-up in dose reporting. The external occasional workers in NPP's receive the largest fraction of dose during outages. They are protected however at each plant by stricter limits than those set by the national authorities, but not necessarily cumulative and trans-boundary.

Utilities kept average doses below 0 .5 mSv and had no individual doses higher than 10 mSv since 2006; a remarkable result of optimisation of protection.

[19] http://www.psandman.com/#by

The Belgian regulatory authorities were not competent for dose registration of all nuclear workers and could not present (contrary to other European nations) the yearly data in due time. This is recently reorganised through better coordination with the Ministry of Work. The EC still fails to implement a European dose passport, as defended by Unions since 30y and made operational by a number of nuclear companies in order to monitor dose of trans-frontier activities. The EC simply has no electronic registry of doses for trans-frontier workers in the globalised nuclear industry.
The most important dose contribution in the nuclear fuel cycle for workers relate to miners and radon outside the country. Due to increasing efficiency of mining this improves but there still exists a large variety in working conditions in particular in developing countries.
The first dose indications recently estimated from U mining areas in the former Belgian colony are high, pointing out residual contamination in living areas. The radioactivity taken up by the population living around necessitates concern. This problem is not only related to radium but also to a range of heavy metal pollutions.

Economic evaluation of nuclear costs

Within the limited capacity for WP4 this aspect could not be developed in relation to Phase-out. For more complete Phase out implications at economic level reference is made to the final GEMIX report. The provisional report "Quel mix énergétique idéal pour la Belgique aux horizons 2020 et 2030"of L. Dufresne et al, ordered by Energy minister P. Magnette was briefly commented on September 15 to the Steering Group). It is interesting to frame this report in the EU PINC (Programme Indicatif Nucléaire Cadre) of EC, communicated to the EU parliament in 2008, yielding European nuclear data for the same period.

A new comparison of costs for electricity production was reported in 2010 by the dir-gen of OCDE, Echevarria at the ENS conference in Barcelona. It presents a sensitivity analysis pointing out that nuclear can be cheaper as well as more expensive than coal (with carbon measures). Nuclear costs between 59 and 99 $/MWth. It has on the average a 59% investment cost, 26 % maintenance cost and 15% fuel cost including 5% for waste and gas.
The future costs will depend on nuclear industry efficiency with an availability world average of 81%, much lower than Belgian results.
Renewables are not competitive for base load; minimum prices for wind are equivalent to maximum prices for nuclear. Nuclear is dependant from governmental support to decrease its investment cost and from carbon reducing incentives. Financial costs dominate the picture; nuclear is cheap at 5% interest rates but is no longer attractive in Europe at 10% rates but should remain attractive in Asia.

Uranium resources are abundant for 100 to 300 y which could be increased with a factor 30 in case fast neutron breeder fuel cycles become available in the long run.
Nuclear has considerable advantage in its low CO2 equivalent production but Nuclear can only contribute 1/3 of the needed CO2 reduction efforts and should be considered as part of the solution following OCDE together with higher efficiency and renewables. Echevarria concluded that nuclear renaissance is not yet realised but prospects are good with a minimum of 600 reactors in 2050 and a maximum of 1400 compared to the situation of about 370 GWe or 436 reactors in 2008 (21.5% nuclear electricity in the OCDE, 14% world wide). The nuclear situation in the world can be considered approximately as a stand still over the period 1990-2030 but from then on the most optimistic scenario expects 50 new reactors/y, with an expansion factor of maximum 4 at the horizon of 2050.
Finally OCDE announced a multinational design evaluation program (MDEP) to arrive at a common approach for safety of new reactors in the market. Belgium is not participating yet**.**

It should be noticed that on the other side as discussed before that nuclear energy is releasing huge quantities of radioactive noble gases and tritium to the atmosphere sometimes up to the authorisation limits as well in NPP's as in reprocessing centres, while end of pipe technology is available to reduce these short and medium living radio-nuclides considerably at marginal costs.

Nuclear waste societal interactions abroad

An IAEA TecDoc (IAEA,2007) document gives an overview of social and political factors interacting in decision making and is discussing some progress in countries with successful as well as failed Nuclear Waste Management (NWM) policies.
It concludes that solutions are technically feasible in future but successful implementation will depend on the integration of social, economic and ethical factors.

The German story of failure of different projects and related reprocessing is interesting. Transport was the Achilles heel focussed by opponents but technical results too were disappointing in salt geological conditions. NWM was and is the driver for nuclear phase out in Germany.

The Obama administration in the USA gave a new direction by halting the foreseen Yucca Mountain disposal authorisation process. The Yucca project for spent fuel (SF) disposal started in 1987 and was financed by funding of nuclear utilities through a tax /nuclear kWh. The objective was to dispose 11 000 containers in 70 km² galleries 300 m deep under Nevada desert (old volcanic dry rock). It costed 10 B$ and was contested by geologists and democrats (Ewing &Von Hippel, 2007), long time defenders of open fuel cycle (OFC; spent fuel) for proliferation risk of reprocessing cycles. Final license procedure was submitted to NRC in 2008 by DOE without EPA final criteria. The split of competencies over different agencies was a negative element in the US. Meanwhile spent fuel is stored on site or in S-Carolina and Washington State in dry storage conditions. A controversy is going on after the negative intervention of NRC commissioners (2009). The administrative court judged on 30/6/2010 that the government alone could not decide to abandon but congress should agree based on the Nuclear Waste Policy act of 1982.
It is not yet clear if the government will redirect US fuel policy towards reprocessing and recycling. Gen IV fuel cycles inspired by France aim at convincing US to build a reprocessing centre in future which will take any way a long time period.
Meanwhile utility funding based on tax contrary to Belgium accumulates.
The original US approach was mainly based on economic arguments that the OFC is likely to remain significantly cheaper than recycling CFC closed fuel cycle either in LWR's (as MOx), as in fast breeder reactors (MIT, 2003, and Bunn, 2003) even with substantial growth of nuclear energy.

A recent overview of US policy before the Obama decision on Yucca is given in (Solomon, 2009). It compares two interesting evolutions in Europe and Canada also on participative democracy. Typical for the US and contrary to Europe is that only the federal state can take decisions and has to solve HLW disposal problems while LLW can be handled at State level. It concludes that the US focus on a single site is unnecessarily risky. It is single minded HLW disposal programme without back-up. There is now a considerable waste flow problem which will continue to accumulate for decennia. It necessitates the extension of on site storage by utilities and the decision on a centralised monitored retrieval storage (MRS), an on-off discussion since 25 years. The global nuclear initiative for Gen IV will not solve this for the next decennia if ever.
Solomon (2009) questions now whether national responsibility for nuclear waste can be universally maintained.
Compared to the EU situation, the EC draft directive for nuclear waste management is however proposing to make HLW programmes mandatory for the member states while the US is still looking for one federal solution for HLW and not at state level.

As a final reflection on US, the legal basic principles for RWM (NW public law 97-425) of the Congress contain a last surprising stating that "*appropriate **precautions** must be taken to ensure the public health, safety an environmental protection for this and future generations*".

Intergenerational equity and value systems for Fuel cycle pathway elements

The Dutch ethicist Benham Taebi (Delft Univ.Techn.) (Taebi, 2010) assessed waste policies in a theoretical philosophical context as a PhD (Taebi, 2010). He develops a normative framework for the moral evaluation of sustainable ethics in nuclear developments based on trans-generational justice and is inspired by the work of Axel Gosseries from UCL (2008) discussed in (Eggermont, 2007).
Taebi states that a closed fuel cycle (CFC) improves sustainability in terms of supply certainty of U and involves less long term radiological risks and proliferation concerns but compromises short term public health, safety and security due to separation of plutonium. The trade-offs in nuclear energy controversies are reducible to a key trade off between present and future. To what extent should we accept additional risks by taking care of our waste at present to diminish exposure to these risks in future? He argues for trans-generational equity by investing now in CFC and in future technologies such as P&T which could be able to reduce substantially long term waste volumes and radio-toxicity.
But as discussed in later in this work (VI) it is still in its infancy and needs serious investments to be further developed. **P&T investments are only justified if the closed fuel cycle is chosen which is not yet done or reconsidered by Belgian parliament. Taebi considers the present P&T programmes as a an extension of earlier CFC options**.

Applying the latter logic to Belgian nuclear policy illustrates the contradiction and incoherence of nuclear policy. Belgian authorities stopped the reprocessing of spent fuel (due to Parliament intervention). MOx recycling in Belgonucléaire was stopped due to AREVA take over and fast breeder research with France and Germany. This was halted for reasons of budget escalation and refusal of the utilities to take part in the financing. Without reconsidering the mentioned policies in Belgian Parliament SCK now develops one of the most ambitious projects of P&T (MYRRHA-SCK). No public debate was organised yet on this policy change.

Taebi is inspired by the ideas of John Rawls on distributive justice. He criticizes NEA for neglecting the distribution of benefits and burdens in case of reprocessing, also in relation to transport. He compares NWM with social security which he considers as economically ineffective but as a duty of the state. He proposes to consider affordability to adapt the NEA criterion of economic efficiency for moral sustainability reasons. He mainly introduces a time dimension in equity in order to choose the pathway element OFC vs. CFC. Intergenerational justice is considered regarding the settlement of value conflicts. The crucial question then becomes how we can equitably transfer a whole waste management system to the future. His answer there only treats part of the problem and neglects historical evidence and financial guarantees.

The first weakness in the work of Taebi is the lack of taking into account historical lessons from FC developments such as clearly analysed in Belgium and abroad (Laes, 2007).

The first generation P&T development is *déjà vu* and has cost a huge amount of 'tax payers' money. If not stopped in 1990 the breeder adventure had made impossible the financial backing of the reorganisation of SCK after its waste scandal.

Some companies and France had mobilised some Belgian politicians through SCK to continue such R&D while being constrained by growing investments and problems of confidence (Laes, Eggermont, et al, 2007). The same technical-economic difficulties occurred in Germany (Kalkar) and in France with Superphenix, where the fast up-scaling of Phenix FBR had to be abandoned.
Belgian recycling technology was already an R&D success at world level but was taken over from BN by France, leaving a waste heritage (particularly rich in actinides) to the Belgian tax payer(alpha containing waste). This created moral and economic challenges in LLWM, complicating disposal of LLW at the surface for 300 y in a densely populated area. (see waste plan NIRAS). The neglected waste implications of multiple experimental set-ups in BR2 needed tax payer expenses and the sodium waste treatment is still a problem to be solved. Moreover prospects of multiple recycling were not realised due to contamination problems as well in enrichment plants as in reprocessing. A life cycle analysis of related problems of recycling in the whole fuel cycle was not made as sustainability (and precaution) requires. Sustainability in the NFC is much more than U resource availability as Taebi suggests. It also requires a responsible management of the full product line of U and not only on its residuals and by-products after a reactor fuel cycle in the own country.
The whole history of FC controversy learns that many beautiful perspectives were created as much as hidden agenda's. The major point is the time scale over which period results of recycling and breeding can be realised. CFC with breeder economy is a story of a century of huge recycling phases. It aims to correct the inherent very low resource efficiency of LWR Gen II/III reactors (1% efficiency). In fact an exponential growth of nuclear spent fuel production in parallel Gen II reactors was assumed already originally. This frames within the logic of exponential energy growth. In future again the real nuclear challenge will be the equilibrium between Gen II and IV over a century. But this approach of nuclear energy can only be used for base load electricity production constrained by societal development requirements for sustainability.
Energy production is only a means and not an objective as such.
Recycling had its limits in Gen II. FBR and Pu quality is degrading in relation to its irradiation. The increasing presence of even Pu isotopes is perturbing fuel cycle efficiency.

Taebi is not considering the U waste, which does not figure neither in the waste inventories of NIRAS neither. Half of the nuclear waste problem in the world is not yet really discussed in the sustainability debate of nuclear waste. It relates to the huge quantities of U mine tailings spread over the world. Real progress is visible in new mining projects. Where remediation has been done as is the case in many site conditions, care should be given for the long term, for risk to future generations. As the source term is long living, sustainability of measures such as tailing pile coverages has still to be demonstrated for more than some decennia. They even should start in some developing countries. Even in France 210 former mine sites create increasing concern for AREVA. The source term is also long living radioactivity and mainly determined by the radium (Ra-226) gaseous decay product radon (Rn). Lung cancer risk from Rn has been re-estimated recently as a real long term health risk for the public in general (10% of lung cancers in Belgium are due to Rn in buildings) (Vanmarcke and UNSCEAR, 2008). Rn in mines and related industries is still the major concern for risk at work in the whole nuclear fuel cycle industry.

Taebi only regards U in the final fuel bundles coming out of reactors. He argues that radio-toxicity and life time of waste can be reduced to uranium equivalence after 5000 y, while recycling U & Pu in a once through cycle, as applied for part of Belgian spent fuel in the past. He reminds that FBR, proposed in combination with Gen II, aims to bred almost all non fissile U-238 to Pu-239 in order to use it as fuel. It allows to reach a supply certainty of 2500-6000 years (IAEA).

These valuable controversial argument are however incomplete. Taebi is not discussing the problem of depleted U around enrichment plants. They are stored in non sustainable containers for some decennia waiting as originally planned for reuse in breeding mantles. U soil contamination is now a public environmental issue in the Rhone valley already.
This is one of the main reasons French (and American) nuclear industry is considering for reinvesting in breeders because. This problem was not internalised in kWh cost in the past and could need serious efforts in OFC to be solved. The use of uranium by products in missiles and civil aviation as done by USA but not strictly allowed in Europe has received already a lot of environmental criticism. Considerable uncertainties remain for health effects (Battle field in Irak & Kosovo; the Bijlmermeer accident (1992).

When comparing radio-toxicity Taebi should us more criticism on data and units used.
Nuclear waste disposal management remains a requirement independently of P&T due to long living fission products such as I 129 which can not been destructed.
Waste in concentrated form cannot be compared to uranium as terrestrial resource; waste components are other chemical products and emit differing kinds of radiation; they are not nature. Moreover nature can be dangerous in many conditions as the radon problem in houses has demonstrated through pooled epidemiology worldwide.

For radiotoxicity the use of the Sv as unit as done by Taebi is not relevant. It is not measurable in the environment and this concept was not developed as environmental effect indicator. It should not been used as an indicator to marginalise health effects.
Taebi is not discussing another crucial reference of radiation protection. The Radiation Protection system is only considering short term effects (even for cancer effects for insuring projects). Authorities are still refusing a ecosystem approach for regulating long term effects instead of the pure intra-generational value reference of anthropocentrism in nuclear risk management.

Taebi is not discussing the Achilles heel of European CFC waste management, the lack of quality control of waste packages, which forms a intergenerational challenge for successful disposal at covered prices.
Taebi neglects the fact that independently of fuel cycle options or new R&D P&T strategies for future, all countries having organised nuclear reactor production, are faced with waste which can only be disposed as such without perspectives for treatment in P&T.
NW disposal is required anyway this century in many countries or in a regional disposal site. An international solidarity to look for different waste host rocks which are best adapted following generic criteria for different waste forms should be the most rational solution at European level. These solutions could be financed by the major European waste producers applying equity criteria and related cost sharing. Such solutions were refused up to now by national authorities fearing local opposition for solutions for global problems. Some countries are not respecting trans-frontier equity, such as France, which is protecting its nuclear utilities. These are producing waste outside the country while refusing waste return of these activities to France.
Small countries still need to develop a subeconomic national disposal project (more expensive per unit of waste due to small scale of disposal project) in less favourable geological situations. This practise conflicts with intra-generational equity at European level.

USA, Canada, Finland, Sweden and the last decennia in particular also Belgium advocate the OFC without really transferring all the risks for the long time period (10-5 to 10-6y) to future generations.
In the most successful countries realising CFC, such as France, a demonstration of feasibility of long term waste disposal is still required. The waste quantities are slightly reduced while producing more intermediate and LLW and necessitating more transport and related proliferation and accidental risks.
Recycling has only been demonstrated industrially for one cycle. Almost no reduction of long term radio-toxicity occurred in the waste but due to higher burn-up longer cooling times are required as complication.

Taebi recognises that proliferation remains the leitmotiv and main objection for CFC. This subject is well developed by numerous artcicles of von Hippel from Princeton (Ewing, 2007) and still requires more efforts as the NIRAS waste plan puts forward.

Intra-generational distribution aspects have always dominated conflicts between nations. Taebi neglects the economic aspect of intergenerational equity related to NWM where sufficient funding or financial guarantees are not yet provided to face the major financial uncertainty for future generations. In many countries confronted with national residues (waste) of globalised electricity production and mining activities, insufficient international legal guarantees exist while the application of international liability regimes is delayed for waste and not sufficiently covered.
The EC draft directive for nuclear waste disposal is not solving this issue. (EC, 2010)
When full transparency should be given on the financial issues acceptance of the accompanying uncertainties could be reconsidered.

CFC will finally require more centralised (continental) plants for reprocessing (and enrichment) with less regional socio economic distribution effects as discussed in VI.

El Barradei stated in 2004: *We should consider limits on the production of new nuclear materials (the enrichment, reprocessing), possibly by agreeing to reduce them or to bring them exclusively under multinational control. This is the main reason why USA, Canada, Finland & Sweden have chosen OFC to avoid Pu separation.*
Taebi shoud question why EC is not applying its competences for fuel supply. The EURATOM treaty reserved exclusive rights for an EC supply agency which could not been materialised as discussed extensively at an ULB conference in the early eighties (Pirotte, 1982) in (Vanden Abeele, 1982), still of high actuality when discussing the need for changes in EU treaties and competences in relation to national industrial or military interests.

The very interesting and enriching set of reflexions by Taebi, clearly states that dominating conflicts of interest cannot be settled by a conceptual analysis of the notion of LT sustainability. Internal and external complexities and obstacles play a role together with the lack of clear criteria.
A major obstacle not taken up by Taebi is if the sustainability discussion on nuclear energy production and waste management can be decoupled. The conditional coupling has proven in many countries its capacity to trigger progress towards waste and safety solutions following crisis events. A conditional coupling could be extended to as well intra generational as intergenerational distributive measures irrespective of borders.

It is our opinion as expressed during the interdisciplinary NIRAS waste conference (Goorden, 2009) that globalisation of complexity (e.g. nuclear energy and waste) can only be successful if global regulation in a liberal market in particular at the continental level of relevance (e.g.Europe) acquires an ethical framing with a trans-boundary and trans-generational dimension. This should guarantee a transparent level of distributive justice stressed by international organisations. Coherence in argumentation, consistency in principles and transparency, however, have not characterised NWM in the past.

It is our opinion that the nuclear waste problem of present generations can be solved by geological disposal in different rock structures within one century. When the technical feasibility is confirmed by tests in the pipe-line, disposal projects could be considered to start before 2020 after clarification of residual uncertainties by research demonstration within 10-20 y (ex. Finland, Sweden). This is also the case for Belgium where Boom clay is not an optimal but a reasonable disposal medium of sufficient robustness for Gen II (eventually Gen III) reactors and as well for CFC (single recycled) as OFC. This is economically feasible (approximately 5-10% of kWh cost), leaving a margin for increase. QA however should be assured and be provisioned sufficiently (this is not yet the case!). Funding should be guaranteed by international law also for taking up uncertainties. This can go up to non intended retrieval for remediation. Full retrievability for fuel use is theoretically always possible at the charge of generations taking eventual benefits. New fuel cycle developments for waste reduction should be taken in charge by the involved industry based on the polluter pays principle for complete life cycle waste. New nuclear energy projects should be conditioned by preliminary solving of this waste problem as already conditioned by the Commissie van Beraad Kernenergie in 1976 and by distributive justice in all aspects of regulation.
Launching nuclear renaissance before solving the waste issue is a delicate option. Considering the large disagreement in society it could be difficult to guarantee politically the sustainability of long term options in a democratic context.
The development of perspectives for waste management improvement by Gen IV fuel cycles in future do not change the discussed waste challenges for this century for waste generated by 50 years of nuclear energy development in the past. Public opinion and policy makers are easily driven by dreams of technological options in the past as well as at present.

Qualitative Check of SD principles related to social interaction

Integration (I) *as principle was not developed in a coherent way through social interaction in nuclear history in Europe in particular. Nuclear economy could not been substantially improved once technology had matured. Communication by authorities has improved following deep crisis moments creating nuclear phase out opportunities and a negative perception in a considerable part of the population. Manipulation of information in public opinion became more subtle. Health and environmental risks remain real with new complexing factors of ethical significance such as genetic susceptibility. The advantages for climate change are real too but uncertainties on atmospheric releases of radioactive noble gases were not considered with similar enthousiasm illustrating the lack of ecosystem approaches in nuclear energy. For nuclear waste a lot of integration experiments failed due to a lack of vision on time scale perception of dis(advantages). Social interaction at work improved but structural handicaps remain (I-).*
Precaution (P) *as strategy for dealing with uncertainties in a transparent careful way was attempted but unsuccessful as illustrated by the many crisis events and lack of public confidence but also by the continuing expert culture of the nuclear sector which is part of the societal problem (Andersson, 2008). Structured transparency as modelled by R&D is still not taken serious to realise a cultural transition. Transparency is the condition to offer different justified interpretations of risk assessment as put forward by the work of Anderson for communication and by Taebi arguing for trans-generational justice in waste management (-).*

Stakeholder (S) **participation** *has progressed but only at opportunistic levels where acceptance is blocked such as local NWM and almost not or only formally through EIA in reactor projects. NIRAS took the lead however at national level for an original approach in HLWM (S+-).*
Distributive E**quity (E)** *remains a major challenge on which future R&D should focus. Financial guarantees and trans-generational equity should be given much more attention. Fuel cycle options are re-discussed but coupled as condition for new projects. Funding should be fully transferred to the State supervised by Europe (E-).The real challenge is with the EC which should dare to develop itself a more ambitious nuclear waste and safety policy.*
The nuclear opponents in a number of countries had accepted to participate in constructive participatory dialogue in order to arrive at nuclear waste management options but are now reacting when the perspective of a long term nuclear waste solution is used for arguing PLEx or new build reactor expansion before solutions are demonstrated. For the UK expert on nuclear controversies Blowers the first blush of new approaches to policy making is coming to an end for revival of stakeholder disaffection and technocratic domination again. For Jugen Hacke, the expert of Jülich at the Gen III seminar of SCK , nuclear renaissance is not yet a fact due to such socio political boundary conditions and considering broader energy market trends influencing public acceptability.
***Global (G)** responsibility taking has not accompanied pace of technological evolution. Business confusion still dominates. It was not possible to transfer differentiated national responsibilities to the European level of relevance while international network collaboration improved (G-). Europe strongly supports future developments (Gen III and IV) without being able to remediate the lack of harmonisation of nuclear safety and European collaboration in waste management. The nuclear waste draft directive of 3/11/2010 is only a small step forward, lacks ambition and is not solving major life cycle issues of nuclear fuel (uranium environmental problems) and equity problems (directing sustainability responsibilities of European utilities).*
European RP initiatives still meets real difficulties such as the international radiation passport which has been delayed for 3 decennia. No European dose registry exists yet for the globalised workforce in European plant maintenance and construction. While the external workers are the majority in nuclear energy no transparency exists yet at international level on their share of risk (G-).

V. Generation III reactors

V.1. Pathway analysis for EPR and other developments:

Pathway: *EPR is an advanced optimised version of the European pressurised water reactor for centralised base load supply of electricity production of large scale. The aim is to present an competitive model for gradual replacement of the present reactors fleet on the European &USA market and for booming economies is Asia for operation between 2010 and 2100. Competitiveness is addressed by upscaling (1650 MWe), by the cost-reducing economies of scale, by increased reliability, by reduced authorisation time and by strictly limited construction time (lowering investment costs). A slightly optimised fuel management remains based on low enriched U with open or closed cycle. Most siting of planned EPR's is foreseen on already existing nuclear sites of Gen I&II reactors.*
A longer life time of at least 60y is considered as more sustainable. Full replacement of parts is possible except for the core pressure vessel and containment building. Key objective is the reduction of severe accidental probability and external environmental impact. This acceptability factor is addressed by many safety improvements of PWR reactor concepts. Moreover RA emissions in air and water are reduced to marginal levels. Nuclear growth is expected globally for climate reasons considering population growth and related energy needs. Smaller scale inherent safe reactors are considered only very recently as alternatives for EPR in competition.

This vision is in perspective of a sustainable future not fundamentally different from Gen II PWR, except that no radioactive pollution should occur, even in accidental conditions. The sometimes applied sub-classification in Gen III (meant for the improved concept of present Belgian reactors) and Gen III+ (EPR, etc) has no significant meaning in a sustainability context (SCK, 2010).

EPR (AREVA)

The safety approach of EPR is based on continued safety and economic improvement of French Framatom N4 (Chooz A &B) and German Konvoi reactor concepts. The development was made by the consortium AREVA and Siemens. The latter being responsible for the classic part on the first construction in Finland, has meanwhile withdrawn from nuclear collaboration.
This EPR development aimed to present an up-scaled alternative from 2010 on, for the replacement of present Gen II reactors after their original supposed life time of 40 years or more. EPR is intended to operate in an optimised way for MOx use (recycling design aim). EPR offers a high load flexibility following operation, with an ability to return to full power. This is an important factor for the French situation above base load of more than 70% nuclear capacity. EdF, the largest nuclear utility in the world, in particular, is confronted with a present need of 2 billion € investments/y, (more than 4 times past investment rates) in order to prepare the renewal of its large nuclear fleet of 58 nuclear reactors (on a total of 436 operating in the world).
EPR should be inherently safer than Gen II, integrating already earlier improvements for Belgian reactors (such as double containment resisting large civil (and military) aviation

impact). The EPR has more safety in depth measures and an increased thermal inertia in emergency cooling. Digital control and automation with analogous back-up is new. Moreover a core catcher has to prevent major melt impact in case of severe accident such as pressure vessel rupture. The new steam generators allow to increase efficiency to 37%. A core reflector allows a slightly better use of uranium resources with higher burn-up. On line maintenance allows to decrease operational costs with better use of uranium. New concrete pouring technology is applied for the containment building (total 1.8 m pre-stressed concrete), mainly for better resistance to earthquakes.
AREVA is the major manufacturer at present of EPR. The technology is meeting the European Utility requirements while EC requirements are lacking.
This reactor has 4 independent safety injection trains builds around the reactor in separate constructions. The promising steel alloy material evolution in fuel rods aims 60 y and more operation with less fission gas releases.

AP 1000 (Westinghouse-Toshiba)

Another reactor development of Gen III occurs in particular within the American Westinghouse strategy where the smaller AP 1000 reactor was certified by the US regulator (NRC) in 2005. This concerns advanced PWR reactors developed in collaboration with Toshiba (Japan). 4 units are being constructed in Sannmen, China (aim is in 60 months). The UK licensing process is ongoing. The advantage is the shorter construction time of theoretically 36 months (compared to 54 months for EPR), theoretically defined from first concrete pouring to fuel loading. It is a modular composite construction with a particular resistant reactor dome and tested passive containment cooling systems certified by NRC. This reactor could be more adapted for smaller grid requirements than the huge EPR. It has, alternatively to the core catcher, an in vessel retention system with heat transfer mechanisms. Moreover it has a passive containment cooling through heat removal by natural circulation.

ATMEA (AREVA-Mitsubishi)

The other alternative considered as Gen III is the ATMEA reactor, a 1000MWe project with construction time of 40 months. This is a venture between AREVA and Mitsubishi, where SUEZ has expressed growing interest. It has advanced safety injection systems and fast start diesel generators. ASN is reviewing the safety options for this reactor by 2011.

The progress on reactor safety with Gen III was and is an important priority for DG Research, in order to reduce core melt and severe accident consequences, as discussed at the EC FISA conference in Prague in June 2009.

Fuel cycle considerations and waste production

The waste perspectives are slightly different from Gen II reactor fuel cycles (Volckaert in SCK,2010, Top Day Gen III). Physical data are only available yet for EPR and AP1000. No comparable economic data for different countries and waste management scales exist.
Waste generation is proportional with spent fuel quantity and with the number of fissions. There will be less waste in the front end of the fuel cycle due to more efficient U resource use (up to 15 more) but higher enrichment (from 4 to 5%) will not create a gain in waste at the front end where more depleted uranium occurs.

Higher BU[20] and longer cycles(18-24 m instead of 12m) create more activation products and more actinides on the contrary. Another required cladding with Nb alloy creates less cladding waste in volume but more activation with Nb-94. The burn-up has no influence on the fission products/TWh but there will be only 10% less fission products /TWhe.
In Gen III the energy efficiency will be about 36-37 % against 30-33% for Gen II.
After reprocessing the quantities of high level vitrified waste are proportional with the the fission products/TWhe (10% lower in Gen III), but the radionuclide content is proportional with burn-up, so this will be more radioactive and requiring longer cooling times or a larger underground disposal surface.
Operational waste from Gen III is expected to improve due to better fuel behaviour and corrosion resistance but this has to be empirically demonstrated. An higher availability of more than 90% is expected instead of an average of 85% for Gen II due to less maintenance. The last 20 years the operational waste quantity generation of EdF has decreased already a factor 4 to 5 and the improvement is expected to be less than differences among countries.
Finally for decommissioning waste significant less quantities are expected as Gen III reactors could produce 60-80% accumulated electricity over their supposed longer life time with less construction material/GWhe.

V.2. Overview of particular leading Gen III developments

Ongoing comparative approaches of the European pressurised reactor (EPR) of the 3rd generation with other Gen III alternatives, such as for UK, could enrich the SD assessment in the near future.

Illustrative Finnish pathway in Olkiluoto

Finland produces 28% of its electricity in nuclear power plants on 2 sites, as well PWR as BWR. Its technology has also integrated successfully Russian elements (horizontal steam generators). Finland had an excellent capacity factor with its Gen II reactors: since 10 years more than 95%. It was the first country opting for the EPR Gen III technology. The contract for building an EPR was made with AREVA/Siemens. It is a turnkey type for which risks of delay are taken in charge by the constructors. The utility TVO, organising the EPR project at Olkiluoto, gives as cost structure for its nuclear production: 60% investment costs, 15% fuel costs and 15% for operational costs while nuclear waste management is estimated at 10%. It is a particular private company grouping 6 industrial shareholders. TVO is selling electricity to them on non profit base but is allowed to sell electricity on the market too.

Finland has also an equal share of renewable electricity production and a considerable part of cogeneration (higher energy efficiency) and depends on an import of 15% of its electricity from Russia.
It aims an emission free energy production and to be self sufficient in electricity production.
It has developed early its regulatory authority and its waste management strategy with established public confidence since decennia.

Construction of Olkiluoto 3 (OL3) started in 2005 on an existing nuclear site where 2 BWR’s are in operation. Olkiluoto is an isolated near island site where reactors can be cooled with sea

[20] BU (burn-up) is the quantity of thermal energy per mass of fuel expressed in GWd/ton

water. Waste management (LLW) is integrated locally at 100m depth in the bedrock. HLW disposal is planned to start as first civil demo plan in the world in 2020 in the deep geology on the same site. This nuclear waste management is carried out by POSIVA. Funding is collected in advance by a State owned fund.
The classic part of unit construction is coordinated by Siemens and was on schedule. The site work was a complex work organisation with more than 50% of construction workers from Polish origin. Organisation difficulties occurred with the French nuclear project leader. AREVA was confronted with a strong and prepared regulator having build up experience on other technologies before. STUK, the regulator aims a transparent regulatory process keeping environmental releases at a marginal level. Even for tritium only 1% of authorised releases are expected. In Tihange and Doel this is about 48%. For the short living noble gases targets are much better than realised in Doel at present.
There is now a delay of more than 3 years; recent estimates foresee that the plant will become operational in the second half of 2013. The cost has increased from 3 billion € to 5 billion €. For this reason AREVA had to take provisions up to 2.7 billion € (last increase of 400 M€ early July 2010, while obtaining a State Guarantee of French government of 610M€. AREVA is no longer rated A by Moodey's for loans on the financial market.
There is an on going liability controversy between AREVA and Finland for the present delay.The French argue that through feedback of the Finnish experiences on the contrary 1 y of construction time could be recuperated in future schedules of EPR.
Finland is considering the construction of a second Gen III reactor now regarding also the alternatives for EPR i.a. the Westinghouse AP1000. The Finnish parliament voted on July 1 2010 an agreement with this principal demand of 2 utilities for other Gen III capacity.

Other EPR developments in France and abroad

France is facing a shortage of production capacity of 3GWe in 2015 and starts replacement of its Gen II fleet. Planned since 2007 a second EPR is being constructed by EdF/AREVA in Flamanville(Normandy) on a nuclear site with already two reactors. A third is planned to start in 2012 in Penly, more in the direction of Belgium alongside the Channel. Flamanville has now a delay of 2 years in construction and faces difficulties with the French regulator while the overcost mounted already to 1.4B€. ASN, the French regulator has published a memo in November 2009 together with Finnish (Ref.STUK, 2009) and British regulator HSE on the reliability of the command-control system for EPR.
During the ENS conference in Barcelona in june 2010 AREVA & EdF (Ref.D. Mockley) did not create transparency on the situation of French nuclear industry underlining the start in 2008 of the construction of 2 EPR's in Taishan in China. The civil work there is taken up by the Chinese themselves.
The crisis in French nuclear industry became visible through the Roussely Report (see above) of a former director of EdF, now vice president of Crédit Suisse to the president of the republic. WG's were set up to clarify relations between major French nuclear actors all controlled by the government in order to restructure them.
The French DM for the second Penly EPR started by a presidential choice in 2009 to give EdF the project leadership together with a direct share in AREVA while blocking the Penly ambitions of Suez & Gaz de France (GdF) (Bezat, 2010). EdF has been considered by French government as sole reactor operator with AREVA as manufacturer for its nuclear strategy notwithstanding European competition rules. AREVA was confronted too with controversies in France on the state of the environment around its 210 former U mines and concerning

ground water pollution near the enrichment plant in Pierrelatte in the Rhone valley, where incidents occurred in 2009.

The major competitor of EdF, Suez has direct interest in collaboration with AREVA on the a smaller Gen III reactor development ASMEA. It has recently withdrawn its interest in participating with EdF in the Penly project. Suez looks for an industrial Gen III role and not for a financial one. Suez also started to compete with EdF on the Chinese market through an agreement of Tractebel and Belgonucléaire with the China National Nuclear Corporation (CNNC) for constructing a pilot MOx plant of 5-6 tons. This concerns technological transfer and assistance for a Chinese MOx plant intended to be operational in 2015. This contract and a collaboration contract with SCK in MYRRHA (Gen IV) received support of both governments (Be/Ch). AREVA hopes to sell a combined reprocessing-Mox plant of 800 ton (15 B €) to CNNC and negociates also the delivery of 2 EPR's to the Chinese CGNPC.
Competition and respect of free market mechanisms in nuclear electricity business seems still maturing in Europe. The financial extent is huge, while showing the failure of the original strategic EURATOM objectives for the fuel cycle (Vanden Abeele, 1992) and for a common market of reactors.
Morgan Stanley has noticed that the ratio of debts to profits of European utilities is larger than it has ever been.
Due to its EPR difficulties France has lost a bid for 4 EPR‘s in the Emirates where South Korea won the order with the smaller reactor concepts originally conceived in France.
In his 2010 report to the president, Roussely, also asks for a new modus vivendi where the authorities should not leave regulation to a completely independent body (ASN). ASN has 441 agents and was re-established by the law on transparency and nuclear safety of 2006, having irrevocable power in regulatory DM.
For ASN EPR safety levels should also be the reference for PLEx of the Gen II reactors in France in the philosophy of permanent improvement of safety. In USA and UK, relevance of safety rules is balanced more with costs. The present French debate is mainly economic as well regarding EPR competitiveness with 40 to 50% cheaper Korean/ Chinese reactors as regarding the cost level of PLEX requirement for 50 French reactors. The latter varies from 400 to 600 M€/reactor but is much lower than foreseen in Germany. The investment for EdF amounts nevertheless to tens of billion €.
For the France EPR strategy in crisis, a recent American industrial decision was very disenchanting. In Calvert Cliffs (USA), the Constellation Energy group was preparing in partnership with EdF the construction of the first EPR in USA. Constellation could not obtain from US government a loan state guarantee for 7.5 B$ for covering 80% of project costs and abandoned the project. EdF however had taken 49% in the nuclear activities of Constellation for 4.5 B $ in 2008 and is facing now contractual difficulties. The economic crisis and more favourable gas developments were influencing the decision of the US group.

There is growing controversy in France. Opponents grouped in the network "Sortir du Nucléaire" consider EPR as an industrial and financial disaster "archaïque avant d'etre construit, si lourd et compliqué…" while AREVA defends it as the most safe reactor in the world, even post 9-11.
Le Monde is noticing that the image of nuclear "made in France" is suffering; since orders do not arrive, the Concorde idea comes up as a nightmare.

The open question revealed by the Roussely Report and former CEO of EdF to president Sarkozy remains: *Is the French first choice of EPR for nuclear intermediate future not to complex to remain competitive?* The conception means its scale or power level, its robust

containment, its core catcher and its redundancy of safety measures. The complexity is amplified by the multiplication of subcontracting and paradoxically by the lack of common regulation of reactor safety in Europe while Roussely himself questioned the role of ASN and opposed paradoxically a too strong independent regulator within France.
Setting the safety level could mainly determine sustainability in future.

Belgium and Gen III

EdF entered the Belgian market through a take over of the Centrica shares in SPE.
But the major utility Suez and the regulator FANC are not putting forward Gen III options for Belgium in the near future. Suez, owning the Belgian nuclear plants is focussing on PLEx of its Gen II reactor fleet. It made its long term safety review strategy accepted by the Belgian regulator except for its aim to extend operation to 60 years and more. FANC however insisted on continuing its decennial review strategy while policy makers are asked to give guarantees for at least 60 years while the legal base is surprisingly still a phase-out.
The Elysée kept out Suez in the EPR planning in France but Suez wants to collaborate with AREVA in particular in ATMEA projects and expressed interest as wel in the UK Gen III developments, where competition with Edf and EPR will be organised on EC market conditions.
Suez gives further priority to its successful PWR technology and considers to build up experience) through privileged partnerships in the 3 types of Gen III reactors (Ref P. Havard on Top Day over Gen III of SCK (SCK, 2010). In this more diversified approach compared to EdF, Suez will be very selective regarding the 3 types of Gen III in which it will participate as industrial and not as financial partner. This prudent intention to diversify considers also its strategic objectives in the USA. Nuclear should remain profitable for Suez.
Its former project for N8 in Doel in 1988 is now presented in PR already as a Gen III precursor. This proposed reactor had 4 safety trains but no core catcher yet to prevent severe accident consequences for the environment.
The present Gen III projects are preferred in the global strategy of Suez for the improved plant performance and safety design changes with in particular the reduced core melt frequency. The design eliminates or is reducing significant releases of radioactivity (tritium, noble gases).
By the acquirement of International Power in the USA, Suez diluted recently the Belgian nuclear share in its portfolio (6GWe production capacity) from 8 to 5%. By this take over Suez became one of the highest carbon dioxide emitters in the world. Now it aims to maintain a 15% share of nuclear in its world capacity (in Belgium 50-60%) and wants to operate somewhere a Gen III reactor before 2020.

EPR planning in UK

In the **UK** the former government approved in 2008 a programme to replace all UK nuclear reactors (20% nuclear electricity; 10GWe)) by EPR's and AP 1000 units of Westinghouse, mainly by EdF and European nuclear competitors in electricity production (Suez, Vattenfall,…). They have to be sited on existing nuclear sites mainly in the S-E. The government decided to sell nuclear sites, dismantling obligations inclusive, and to leave investments to foreign operators. The 2008 UK's energy act considers developing a site for a new nuclear power plant in England and Wales, without an approved decommissoning programme or failing to comply with it, as a criminal offence. The related liability discussion could become interesting material for legal developments regarding future sustainability requirements in relation to past legacies in nuclear. The aim of the UK government can be

considered as lesson learned from the past. The future operator from abroad should set aside sufficient funds over the operating period of the power station to cover full costs of not only decommissioning but also of spent fuel, waste management and disposal costs (Pyke, 2010). UK is not intending to give public financial support to this nuclear renaissance which should be realised in the market. But as a reaction City Bank decided not to invest capital in these projects without governmental support.
Further DM is dependant on SEA and comparative studies including cost comparisons are ongoing. The Gen III option however remains limited to a replacement of the present nuclear electricity capacity.
Considering its declining gas and oil reserves and intended closure of 8 GWe of coal plants UK could need 25 GWe new generating capacity the next 2 decades. The existing English graphite gas cooled reactors consider more difficulties than PWR to extend life time due to oxidation of graphite in the core (gone).
Nuclear Gen III is now considered by the Westinghouse chair Abram T. (Top, 2010) of the Univ. of Manchester as the choice of the moment for its scale, its safety, reliability, very low carbon emission, longevity and security of supply. A. Blowers, an expert in participation processes in nuclear problem issues in the UK (Sellafield), on the contrary **warns for using waste participatory approaches to support expansion of nuclear new-build**. This will generate more waste before the disposal problem is solved. The new presentation of long term geological disposal as best solution is thus being perverted in favour of non intended support fro nuclear renaissance which brings back the top-down expert driven centralised and closed way of DM.
For the UK 8 sites are recently confirmed for a generic Gen III design with a real need for new built ready in 2020. The UK certification processes for these Gen III reactors are ongoing with difficulties already for EPR (STUK, 2008). It should be noticed that the former national industrial ambitions of British nuclear industry have been suppressed for financial reasons in favour of global entities from abroad.

EPR commitments of the Dutch Government

In the **Netherlands,** Delta (Dutch electricity producer of local communities in international transition) proposed at the end of June 2009 to site at Borsele (Vlissingen) up to a maximum of 2500 MWe nuclear capacity of Gen III safety level with e.g. a core catcher. No approval or agreement was given by the Dutch transition government but a new government decided in October 2010 to construct one or more reactors. The authorisation and construction could take however 12 y due to a lack of safety administrations for this new ambition. The EIA process was started with demand for advise to Belgian nuclear regulatory authorities (September 2009) and participation of border villages in Belgium, including Gent. Siting could become again an issue of interest as in the past since local action groups mobilise again at the Belgian side of the border. In SEPIA this was however not confirmed in exercises as being a concern of experts or selected citizens.

USA Gen III developments

Originally and till last year 4 EPR’s were planned in the USA in cooperation of EdF and Constellation in Unistar. The first start for production was 2015. This collaboration is cancelled now (see France) by Constellation.

NRC, the American regulator hesitates too on certifying EPR on the American market. This is postponed till the end of 2010. The problem mainly concerns the command-control of the reactor, a complex IT system which doesn't have enough redundancy and which could make it difficult to take over the reactor manually in case of emergency. The concept should be simplified.
Meanwhile Westinghouse (US) developed an alternative or supplementary strategy to develop a series of small scale reactors with Gen III characteristics due to a market demand for smaller units and cheaper investments. The US combines these strategies with reduction of fuelling frequency for proliferation reasons, a dominant driver in US sustainability policy.
For California where further nuclear development since Chernobyl is conditioned to solving waste and proliferation issues, a large debate goes on between choices for centralised solar parks up to 4GWe or new nuclear parks.
The USA having now 20% nuclear electricity intends to increase this to 29% in 2030. Westinghouse sees as constraint the capacity factor (lower than in Europe), the kWh costs evolution and the acceptance. This requires competitive costs, certainty on construction schedule and time, increased safety level, standardisation and easier operation and maintenance. The alternative option of Westinghouse is a less complicated modular design. For the acceptance a safe demonstration of the present fleet will be crucial and proliferation risk should decrease. At present also Westinghouse is constructing in China its smaller AP1000 (MWe) series of which 6 units are being constructed in the USA. The system was certified in 2007 and has also a number of advanced safety features. It is now also considered for licensing in the UK.
Moreover gas price and CO2 treatment cost are important factors in nuclear DM.
A larger advanced LWR will be ready in 2013 (1600 MWe) at Westinghouse while a new strategic option for world markets is taken for a small modular reactor at the horizon of 2023 (pre-manufactured). Echevarria (OCDE) stated at the Barcelona ENS meeting that the grid of more than 40 developing countries is only accessible for small reactors as DOE is now pushing strategically in the USA.
Moreover a high temperature reactor for process heat is in project with S-Africa in 2025.
Meanwhile the Obama administration halted the DM process for final disposal of spent fuel in the Yucca Mountains, near Las Vegas, a controversial project since many years.
The deep geological disposal of military waste in salt layers deep under New Mexico (WIPP, Carlsbad) on the contrary, continues successfully.

Russian approaches

Russia recently presented very small floating reactors on ships (Akademik Lomonosov). They intend to support with power supply distant locations such as the Arctic (2X35MW; 534 M $)). 7 ship reactor systems are being build by ROSATOM, in which German Siemens is now participating. It addresses also demands on Chinese market and for desalination projects (240 000 m³/d) in Africa.

V.3. Clustered factor analysis *I ☹ P 😐 S ☹ E ☹ G 😐*

Reactor technology
Compared to present Belgian reactor performance and operational safety a slight improvement can be expected in the efficiency, life time, safety, waste generation and

environmental risk of Gen III reactors. The core catcher is more relevant for siting in densely populated vulnerable areas. But public opinion could challenge coherence of this more sustainable approach with strategies aiming plant life extension for the same period. For Belgium in particular no Gen III plants are put forward yet, regarding the focus of Suez on Gen II PLEx, but Gen III plants are planned to be sited at our borders.
The integration of European nuclear industry and the respect of market rules seem to fail.

Fuel cycle

Slight changes of resource use are expected in the light of abundant diversified uranium resources for next century.
Conditions for safety at work and environmental protection improve in and around mines without a general overview at UN level (UNSCEAR). The sustainability of remediation measures in uranium mining areas (radon) is still an open question in particular in developing countries while radon risk estimates are higher than before.
The re-exploitation of former U mines in Katanga will require expensive clean up in the future and could overshadow local Belgian concerns on the other nuclear wastes.
Open or closed fuel cycle decisions remain open in Gen III; advanced reprocessing with higher yield of long living actinides will not be operational at industrial level before 2050.
The waste problem remains of the same magnitude. Only practise can truly show, but Gen III could produce only 10-20% less nuclear waste dependant on the kind of waste. Increased MOx use will reduce initial radio-toxicity in the waste due to Pu elimination but fission products remain similar while the heat and cooling time problem increases as related to BU, to Sr activity and to actinides other than Pu.
The cost difference of sub-economic waste management programmes of small countries compared to France in European perspective is much more important than the waste cost improvement between Gen II and III.

Drivers

Drivers are situated outside the nuclear sector (climate, market scale demand) or inside (severe accident prevention, replacement of reactors), similar to drivers of Gen II.
The scale of electricity production is enlarged in case of choosing EPR for Gen III (1700 MWe) with some advantages for load follow up in case of overcapacity such as in France and Belgium.
The market competition of small scale developments in USA and Russia could face the major option of French industry. It addresses local needs and conditions (grid) of important evolving markets with less financial risks related to investment costs. The complexity of EPR becomes a handicap and its future is uncertain.
The utilities face the political contradictions of the liberalised market but will depend on indirect market disturbing measures such as support of nuclear research and carbon taxes. Moreover market mechanisms disturb the reflection of production costs in consumer price transparency.
The economic objectives were not realised up to now due to dominant investment cost escalation and in particular due to delays in construction times, put forward as strategic advantage for EPR. Crucial parameters for competitive advantage (investment cost, construction and licensing time) are critical regarding major concept problems and certification related to safety (IT system). The eventual economic advantage is smaller than uncertainties related to different energy options.

Regulatory aspects

The equilibrium between economy and safety in a crisis period is challenged. The drive for independency of national regulators in France in particular is questioned undermining the coherence of a sustainability argument. The EU is not yet allowed to organise safety harmonisation and safety implementation at continental level.

DG research has set as objective the harmonisation of design certification requirements. There is progress in bilateral safety collaboration and regulatory networking (Safety principles for NPP's of IAEA (INSAG) and the WENRA Reference levels for Reactor safety (2008) aim at improving normal operation, preventing incidents and accidents by reducing frequency of abnormal events and in order to prevent severe accidents (frequency of less than 10-5 /h for core melt) and the need for emergency measures. External hazards should no longer be a major hazard. Siting considerations remain however very important for integration and are not considered in the forefront where European utilities (not EC) has put forward technology system requirements of generic level for streamlining competition. There is an organisation of evaluation efforts at OECD/NEA level in the context of market impact. Although independency of safety evaluation remains a continuous challenge, safety culture should insure the awareness in all conditions but was failing frequently in the past.

Social integration

Gen III development is focussing standardisation of some design with strong competition. Due to a lack of harmonisation at international level each unit remains an individual. Customers such as Korea become competitors. Market uncertainty remains prominent and scale vision remains a delicate success factor. What is the right scale for power supply in the market is particularly challenging for nuclear strategies and requires again the development of a range of technologies instead of standardisation.

Production capacities of the large constructor ventures remain relatively low for nuclear revival except in China where all available options as well nuclear as non nuclear are being developed.

Large differences exist between capacities and forecasts of NPP's. In France with 58 reactors, only 2 are programmed yet against 19/6 for UK 103/31 for the USA, but 32/36 for Russia and 13/103 for China.

A site specific PSA level 3 analysis could clarify the advantages for local DM of Gen III on Gen II and allow a rational deliberation of pathway elements to take options (phase in/out variety in Europe).

In case of contamination of a extended area following a nuclear accident economic and traffic consequences should be given as much attention as emergency planning for population. (Zeeland area e.g. in case of a comparison of an EPR or 2 AP 1000 in Borsele with a PLEX of 1700 Gen II in Doel)

International liability regimes are not yet implemented to cover potential costs and long term effects of larger scale technologies in densely populated areas. Belgium will be in the preferred wind direction of at least 5 EPR's or Gen III reactors before 2030 but of much more and less safe old reactors of Gen II.

Qualitative check of sustainability principles to Gen III

Integration (I)

Gen III NPP's, and in particular EPR, are very large up-scaled machines for electricity production. There is little integration perspective for increasing substantially total energy efficiency still limited to 37%.(I-). There is little progress in requiring PSA level 3 to argue the safety of siting of NPP's for densely populated areas. Existing and future electricity grid integration problems need to be solved or could be worse in case of larger scale plants (I-).They are conceived for a longer lifetime of 60 years with more resistant materials but this is argued similarly for Gen II PLEx.

There is no real progress in the low efficiency of U resource use limited by single MOx recycling (I-, E-) Considering the abundance of resources even for nuclear renaissance this is not yet a real need for this century. It has influence on US DM for a more prudent Gen III commitment.

Discussions on Gen III e.g. safety and protection criteria could be an interesting step forward (I+) considering the international exchanges (concept level of dose for workers, command-control requirements, prevention

severe accident consequences, reduction of noble gas and tritium releases) The latter are not taken up seriously at present compared to climate discourses (I-)
It was noticed that a rather new work organisation related to globalisation and trans-boundary subcontracting is requiring new project management approaches (AREVA). It is illustrating the relativity of regional employment arguments for large investment projects and could oppose national interests for regional (job) incentives in future (concentration of majority of Polish workforce in OL 3).
Within the new socio economic perspectives (reduced growth, increased energy efficiency and decrease of electricity consumption) since the crisis, future renaissance of nuclear is not so bright as it seems in particular for regional economies, but even for USA.
International strategic alliances direct decreased employment opportunities for nuclear industry(Be)(I-).
As the principle of independency of French regulatory authorities was questioned in a clash with EdF the key economic role of safety criteria is illustrated and should be taken up as a serious challenge for European integration and sustainability (I-)
Precaution (P)
Progress in major accidental risk and environmental releases is real (P+) if demonstrated by practise from 2014 on.
The confrontation of an independent national regulatory culture (Finnish authorities) with the leading nuclear company AREVA on the first EPR project has enriched the safety dialogue in other countries but had negative economic impact for France and Europe due to missed global orders. Its economic consequences lead to a questioning of the autonomy of French safety authorities by the EdF utility.
Stakeholder participation (S)
EIA EU regulation allowed to associate the public in new reactor projects but no participative experiments were set up such as done for nuclear waste (S-). Participatory decision making is loosing momentum which could have a drawback on the progress for solving the acceptability of waste solutions. A main question in acceptability seems the (de)coupling of final waste management with new build nuclear(S-).
Equity (E)
The lack of siting perspectives constrains the expansion of NPP's in Belgium and could require more selectivity in technological choices in favour of smaller Gen III options of which the local economic tissue could benefit more(E-). Except for engineering companies the socio economic advantage of Gen II has not been demonstrated yet, while decision making is made in Paris.(E+-)
The controversy on safety approaches has underlined the delicate balance between economy and safety, notwithstanding political discourses. There is little progress in liability requirements for new NPP's at border sites to cover long term effects.(E-)
***Global** approach (G)*
There is a lack of attention for small reactor development in Europe for the needs of internal as well of world markets (G-)
If the Netherlands should decide to install an EPR on the banks of the Schelde river, which is now realistic at the horizon 2022, the ecological (thermal) charge on the river could be constraining for further Belgian nuclear DM regarding Doel, while not excluding international utility collaboration on such international border sites and of Suez or EdF in particular (G+).
Acts of local regulators had due to media follow-up a global impact on competitiveness (G+).
The poor EC competence for nuclear safety in globalisation was illustrated. If this cannot be enforced the negative impact on international competition will be evident (P-, G-).

Gen III can be considered more as an evolutionary process than as a real transition towards sustainability.

VI. Generation IV and MYRRHA

Pathway: *Fast neutron reactor technology for centralised electricity production and advanced centralised reprocessing of spent fuel is put forward as future sustainable nuclear solution. Considerable increase of resource efficiency (security of supply), competitiveness and decreased long term nuclear waste as well as environmental releases characterise the perspective of sustainability as put forward by the nuclear sector. This should be demonstrated by huge national and international programmes of feasibility research and development including alternatives for technological uncertainties.*
Repeated recycling of fuel, fed by sufficient PWR's of Gen II&III and fuel transport to and from reprocessing should support such continental pathway. Priority is given to demonstrate a manageable proliferation risk as important concern.
Alternative (hybrid) technologies for delicate sodium cooling are developed in parallel (heavy metal, accelerator driven systems, gas cooled systems).
Small scale total energy high temperature concepts are given limited international attention but almost not in Belgian R&D (VHTR for industrial process heat and hydrogen production besides electricity generation).
Time scale of industrial demonstration is 2030-2050 and deployment 2050-2150.

VI.1 Pathway analysis for fast neutron closed fuel cycles

Innovative global nuclear energy strategy

At IAEA level an initiative was developed already in 2000 to open sensitive future nuclear tech to third countries: INPRO. The Int. Project on Innovative Nuclear Reactors and Fuel Cycles) groups now 31 countries (16 of the G20 countries) including Belgium and EU. **INPRO** is funded extra budgetary by voluntary contributions of members.

In 2005 a more selected forum for future nuclear development was created in Washington: **GNEP**. This global nuclear energy partnership, was launched by President Bush in order to develop technical roadmaps for a fourth generation of reactors and fuel cycles: Gen IV. The US advanced the idea to regain leadership in nuclear energy technology (Editorial discussion in Nucl. Eng. Int. 2007). It focuses the earlier French nuclear reactor strategy to redevelop fast neutron reactors and related but advanced closed fuel cycles, now taken over by the Bush administration together with some other alternatives. Collaboration was sought with France and in particular with the AREVA know-how which is dominant in this field. The Gen IV international forum (GIF) was created. A roadmap was developed.
The program is joined meanwhile by EC and more than 10 countries including China, India, Japan, Korea but not by Belgium as such. Our country however contributes considerably through SCK in the EC commitment.
The new US president Obama has put the American contribution in 2009 2 y on hold (continuation at constant instead of growing budget) for reassessment, while having halted the Yucca Mountains spent fuel disposal project.

An INPRO progress report was worked out in 2009 in synergy with GIF but including substantial east European experience. It presents 6 programmes and has set up evaluation methodologies such as NESA (Nuclear energy system assessment) discussed by Hugé in SEPIA annex 2.
The INPRO methodology aims at helping countries in the transition of present nuclear energy systems to Gen IV systems using indicators and applying them to 6 areas (safety, environment, physical protection, waste management, infrastructure and economy).

Nuclear sector view on sustainability

The INPRO approach is promising but was not aligned yet on generic sustainability criteria. Some sustainability concerns like proliferation resistance and environmental benchmarking are already applied. Some ongoing scenario work is comparable to exercises done by the Belgian Federal Planning Office and could yield interesting indications for Gen IV. They should be available the coming years. The results of the GAINS scenario could clarify the required growth ratio of fast breeders versus LWR's in the global nuclear energy system (which is however a theoretical concept). The deployment rate of FR will be limited in the long term after 2050 by the availability of Pu In these scenarios. FR could grow from 10 GWe by 2030 to 400 GWe by 2050. The GAINS framework could also be explored for ADS systems like MYRRHA.
It should be noticed that the mission of IAEA is to promote nuclear technology and that attempts were made since more than 15 years to position nuclear energy as fulfilling a number of sustainability criteria. As long as no generic sustainability assessment methodology is agreed at higher UN leveI the sector assessments as done by lAEA have to be considered as partial, given its mission.

In the EU a nuclear energy forum (**ENEF**) was set up by the EC in 2007 to provide a roadmap for the continued development of nuclear energy in the community as set up by the EURATOM treaty. This was integrated in the 20/20/20 objective of the EC (20% better energy efficiency, 20% renewable, 20% reduction of greenhouse gases).
It should be noticed however that nuclear actors usually consider nuclear energy as renewable by definition, consider greenhouse gas as equal with carbon emission, while not regarding electricity energy losses or the framing of electricity use within energy policy demand optimisation.

The **SET** plan (European Strategic Energy Technology plan) was set up to tackle climate issues by an effective low-carbon policy and efficient energy use. The nuclear part of the SET plan is called the European sustainable nuclear industrial initiative (ESNII) and was launched at the SET-plan conference in Brussels on 15 November 2010[21]. It was set up to demonstrate and accelerate technologies. A limited scope interpretation was given aligning preset nuclear strategies. The options were **not confronted with usual criteria for sustainability applied outside the nuclear sector** and in this report. The EC made an impact assessment of this SET-plan after closure of this report as mentioned in (Hugé,2010).
In Europe the nuclear island approach of IAEA within UN is facilitated and even enforced by the EURATOM treaty. The legal framing for nuclear and the own nuclear world view and assessment methodologies of dedicated administrations are not favouring integration of nuclear as illustrated by the ongoing controversy or impasse on the drinking water directive.

[21] *http://www.setplan2010.be/en/setplan2010/presentations/day-1-15-november-2010*

The SET plan aims to demonstrate the long term sustainability of nuclear energy by design, construction and demonstration of Gen IV reactors based on fast neutrons and closed fuel cycles, which is a very limited scope defined in advance. The aim is a 50-100 times more efficient use of U, the generation of less long living waste, the reduction of proliferation risks and maximising inherent and passive safety features. A sustainable nuclear energy technology platform of 80 industrial and R&D organisations from across Europe pilot this initiative for which the EC has estimated a cost of 7-10 B€ (Ref EU, 2010) to be supported by the EC framework program. An ongoing strategic agenda is discussed below.

For Belgium **MYRRHA** presents an ambitious and innovative part which could be inserted within the Gen IV international dynamics. This project of the Belgian nuclear research centre SCK and its involved university professors and political party representatives in its board will be considered and assessed on strengths, weaknesses and lessons learned from the past in order to clarify sustainability opportunities in the Belgian energy context.
For the scope of this report the alternative of HTR developments for Belgian energy supply will be put forward in order to stimulate a comparison and eventual alternative for future EIA and SEA.

The driving forces for all these nuclear strategies are the global climate challenges, an opportunity to present nuclear energy as a part of the future energy mix with a promising technical portfolio, aiming to protect the environment and the ,climate in particular, being economically affordable and facing the socio political boundary conditions, proliferation resistance in particular.

Sustainability criteria (Laes, 2006) such as shared responsibility for sustainable consumption and energy efficiency in a global approach, integration within other compartments of policy making, intra and inter-generational equity, precaution, participation and global responsibility are almost not developed for assessing these nuclear options. Criteria are limited to energy security, resource efficiency, competitiveness, reduction of environmental and proliferation risk. The last being a potential exclusion factor on itself for nuclear sustainability.

This work tries to consider a broader scope of criteria with particular attention for coherence and transparency. As an example the internal contradiction is apparently not addressed that the nuclear sector argues its future renaissance referring first of all to an environmental system impact analysis for the atmosphere (climate) while not using yet such ecosystem approach for its own radioactive gaseous releases. This leads to considerable scientific misunderstandings even at the level of IPCC where nuclear was presented erroneously as not releasing radioactivity in the atmosphere and the oceans.
In nuclear usually only health effects are considered in an anthropocentric approach which allows to marginalise long term effects, which explains the argumentation in the eighties for sea dumping of Radio Active (RA) waste.
Little research has been done on synergistic atmospheric effects, demonstrated to be real in reviewed literature (Raes, 1991).

Historic framing: in search of a déjà vu resource efficiency

The aim of the new Gen IV strategy at least in R&D demonstration is to arrive at better resource efficiency which is very low now as discussed before. By the way it is the aim to reduce long term nuclear waste impact. This could be a step towards sustainability and

contribute to environmental quality while considering the climate challenge for energy production as an external advantage.
Particular attention is paid to the proliferation and terrorism challenges which remain of global treat for sustainability. But the preliminary commitment of weapon states for atomic bomb dismantling in the long run remains the weakness of the non-proliferation treaty.
Even President Obama, who promoted his vision of a world free of nuclear arms which helped him to get the Nobel Peace Prize in 2009, has allowed the US army to carry out a new underground sub-critical nuclear test in Nevada in September 2010. This event has been heavily contested by the mayors of Hiroshima (Tadatoshi Akiba) and Nagasaki (Tomihisa Taue)[22].

In the USA Gen IV was a fundamental political change in this context since the strategic choice for an open fuel cycle was made for proliferation reasons by the Democratic Party under President Carter in 1977 as discussed by (Laes, 2007[23]).
In the EU Finland and Sweden had chosen the American way of open fuel cycle. They have developed a spent fuel waste disposal and site selection programme which is approaching authorisation phase and construction by 2020-30.
Belgian parliament joined this strategy through a resolution in 1993 (Laes, 2007[24]) and has opted for halting reprocessing contracts with COGEMA in 1998.
MOx recycling use in Belgian NPP's stopped in 2005.
COGEMA, now called AREVA, has taken over the Belgian MOx technology and transferred production from Dessel to the south of France in 2006. The Belgonucléaire MOx plant is being dismantled now. The whole research and production of MOx has characterised the Belgian nuclear waste content which has a much larger long living alpha emittor content than waste inventories in most other countries. The residual alpha content in low level waste could be a critical point even after 300 y surface disposal or during selection of disposal mode within some decennia. The economic consequences are discussed in the NIRAS waste plan (NIRAS, 2010[25]).

In Gen IV attention is given not only to sodium cooled fast breeder reactors but also to alternatives cooled with gas or lead. In the eighties fast neutron reactors and reprocessing were already the answer on inefficient U resource use by LWR's. These technologies have not been successful for economic and technical reasons. The UK strategy for breeder reactor development failed after environmental problems with the closure of the Scottish reactor and reprocessing plant at Dounrey but through the US collaboration with BNFL some know how could be transferred to the new US strategy.
The German project of a fast breeder reactor at Kalkar started in 1969 and was stopped before operation in 1991 (Laes, 2007[26]) and transformed into an amusement park. The Superphenix FBR, a too early up-scaling of the French Phenix FBR prototype was stopped later while the Phenix FBR was reopened by CEA. Belgium contributed a lot to this development through SCK test programmes and FBR fuel R&D and development in Belgonucléaire. The international collaboration programme was stopped in 1990 due to escalating budgets (the total contribution was 13 B BF (Laes, 2007[27]). The lack of strategic organisation of Belgian interests versus France and the refusal of the utilities to take in charge part of costs were decision factors.

[22] Hiroshima, Nagasaki ire at US nuke test, AFP, 14/10/2010
[23] p 84
[24] p176
[25] p 164
[26] p127
[27] p 127

The huge quantities of depleted uranium from enrichment plants in particular in EURODIF in the Rhone Valley had originally as destination to be used as breeder mantle in later FBR's in order to generate Pu in successive reprocessing and MOx recycling. It was intended to reach an U fuel cycle efficiency of more than 50% instead of 1-2% now in LWR's in up to 6 times recycling spread over a century, each time by diluting recycled fuel in fresh fuel. In that way OCDE estimates that U resources could be sufficient for 30 times present proven availability of about 100 y. But the PUREX reprocessing fuel cycle technique only arrived at demonstrating industrially single recycling of MOx due to contamination problems by recycled U in enrichment plants and considering the impact of burn-up on reprocessing operation. Moreover the spectrum of actinides during irradiation shifts to uneven isotopes like Pu 238, 240 and 242 less intended or disturbing for fission compared to Pu-239 and 241.

Meanwhile the depleted uranium of Gen II reactors is stored in unsustainable containers on site of enrichment plants abroad. They are not conceived for long term waste storage over more than a century. The Belgian financial and waste liability for this fuel cycle problem is not yet clarified as Belgium is participating for 10% in EURODIF through SYNATOM.
The uranium waste piles around mines and enrichment centres can be considered as one of the most important challenges for sustainability of the nuclear fuel cycles worldwide. Depleted uranium (environmental) liability could be a main hidden driver for Gen IV Gen IV development, where the largest nuclear company in the world takes the lead.
The depleted uranium also from military programs in the USA is used as heavy metal in missiles and was creating environmental controversy after its use in the Kosovo and Gulf wars.
The recently proposed EC draft directive for waste disposal is not considering uranium problems yet (EC, 2010).

Gen IV international forum (GIF)

In Gen IV at international level 6 options have been selected for further research: very high temperature reactor (VHTR), gas cooled fast reactor (GFR), Sodium cooled fast reactor (SFR or FBR), lead-cooled fast breeder reactor (LFR), molten salt reactor (MSR) and super critical water-cooled reactor (SCWR). (Abram T., 2008)
The EC nuclear framework programme and DG TREN took the lead in European coordination within GIF. The EU options are mentioned for completeness in the EC program chapter.
Three options are relevant for Belgium and are discussed here. It concerns fast neutron breeder reactors cooled wit liquid sodium, the alternative fast neutron source cooling with liquid heavy metals, eventually driven by accelerator systems (ADS) and intended for transmutation or as burner of minor actinides.
The Belgian MYRRHA system belongs to this family. Finally there is the total energy concept of (very) high temperature reactors (VHTR), which is of interest to the Belgian metal industry federation Agoria expressed interest.

EU strategic nuclear dynamics

A vision report of EC DG Research in 2007 has prepared the launch within the framework programme of a European Sustainability Nuclear Energy Technology Platform (SNE-TP).

It proposes roadmaps for a strategic research agenda to maintain European nuclear leadership in the world (31% nuclear electricity or pretended non emission of 900 M ton C, without considering efficiency and counter productive demand effects).
The progress on this financially very important new priority was discussed at the EC FISA conference in Prague in June 2009. A strategic research agenda (SRA 2009) for SNETP was put forward. The vision report is asking the nuclear sector to address three objectives:

- maintain nuclear safety and competitiveness
- develop a new generation of more sustainable reactor technologies, so called Gen IV fast neutron reactors with closed fuel cycles
- develop new applications of nuclear power such as hydrogen, desalination & industrial heat

The EC will support such a role of nuclear energy in Europe's energy mix in order to contribute to security and competitiveness of energy supply and to reduction of greenhouse gases (see SET plan discussion above in nuclear sector view). Besides fast neutron systems and closed fuel cycles continued attention will be given to LWR's (Gen II and III) which should supply recycled fuel for fast reactors. From 2040 on fast reactor should operate in parallel with Gen III reactors maintaining the current 1/3 share of nuclear electricity. The technical feasibility and safety of geological disposal sites is considered undeniable with demo in the EU within 10 years. But to increase sustainability more efforts should be dedicated to advanced fuel cycles for P&T. They will enable reduction in volume, in thermal impact, in radioactive inventory and in longevity of ultimate waste for disposal in a geological repository.
The EC supposes a likely increase of electricity demand at the horizon 2050 in particular for the transport sector where also hydrogen could contribute.
The EC is clearly positioning its own priority for fast breeder reactors within GIF; it considers European sodium cooled technological development of the past as a proven concept which should be redesigned to adapt to today's operational, safety and competitiveness standards. Simplifications are necessary in the primary system; materials and system parts should improve (heat exchanger, instrumentation and inspection) with enhanced safety. A demo prototype is build in France by 2020, (ASTRID).

Lead cooled and gas cooled fast reactors (GIF) are given less priority but a choice of one alternative for FBR (SBR)[28] should be made in 2012. For transmutation purposes the ADS[29] technology should be compared with FBR as fast neutron source. MYRRHA should become an experimental demonstrator of this technology with assessment from economical point of view of its contribution to closure of the fuel cycle. Belgium in particular took the lead in such developments.
Fuel cycle research is needed for Gen IV fuel fabrication as well as for advanced reprocessing.
The safety research for long-term operation of reactors and in particular for the design of an intrinsic safe FBR will require a lot of efforts. European standards are needed by pre-normative research.

Total energy concepts: the (Very) High Temperature reactor

Side attention is given to high temperature heat processes in order to substitute fossil fuel based industrial processes. The SFR is not intended for temperatures above 500 °C. A number of other energy applications in the range 800° to 1400 ° range from town gas, chemical industry, coal gasification, gas turbines for electricity to iron, cement and glass

[28] Fast breeder reactor (FBR) or sodium cooled fast reactor (SFR)
[29] Accelarator driven system (ADS)

manufacturing. These process heat could be supplied by (V)HTR's for which a prototype should also been build around 2020 and where AREVA develops a reactor concept; the coupling of such a reactor to industrial processes is the main challenge but there are also material requirements, fuel improvement and graphite waste management efforts needed.
A sustainability assessment of the latter including alternative thorium fuel cycles is planned in the EC CARBOwaste project. An EU network prepares licensing requirements for this reactor.
It was not possible within the limited scope of SEPIA to assess more in depth both the Th fuel cycles as HTR. These are based on already tens of years of research and demonstration worldwide and networking even for preparing the licensing base.

Finally the whole Gen IV programme requires support of **basic research** to clarify cross sections, material strengths, etc. and also test irradiation facilities such as BR2 in the past. For this purpose the Jules Horowitz material test reactor is being build in Cadarache (Fr) since 2007 while MYRRHA and a new reactor PALLAS in Petten (Nl) could give support, also for providing medical isotopes.

The financial impact of these programmes is huge also for the side roadmaps as MYRRHA, discussed below and which will cost at least 1B€, more than the already ambitious Jules Horowitz reactor for France, having the most developed nuclear industrial tissue in the world. The commission is only taking in charge part of the investments which requires international consortia to share participation and risk of national entities.

Technico-strategic issues of relevance

The closed fuel cycle with a synergy of breeders and LWR's is now been given an aura of renaissance through the improvement of advanced reprocessing (called partitioning). This intends to separate not only U and Pu for recycled use but also minor actinides (Np, Am, Cm) in order to transmute them through reactor irradiation into radionuclides of shorter half life time. A particular advantage could be the long term waste reduction which is presented sometimes for PR reasons as elimination of long living waste of more than 1000y concern.

The complexity of chemical operations requires a centralised proliferation resistant industrial plant. Spread reactor production and irradiation will require multiple interna-tional transport operations and consecutive recycling phases spread over a century in order to obtain this trans-generational advantage of more efficient resource use.

Sodium cooled FBR
The reactor cooling technology of liquid sodium is delicate for accidental reasons and requires complex safety in depth measures which have increased cost considerably in the past projects. There was considerable experience realised in Russia and India with few transparency on economic perspectives, while Japan worked out a FBR and reprocessing technology under French contracts.
A higher resistance will be required for external hazards, earthquakes and plane crashes in particular while economics require reduced investment costs and high availability factors with easy maintenance. The flammability and water reactivity of sodium is a particular safety concern, which could as in the past create public acceptability problems. Here a precaution strategy will be needed as an inherent aspect of sustainability but **precaution** as a criterion is not even mentioned by The EC authorities in the nuclear sector.

Precluding large energy releases in case of severe accidents will need advanced core and vessel design to disperse core debris.
The reduction of proliferation risks considering the complexity of fuel used is a challenge less open for detailed discussion; the licensing requirements and proliferation case of new systems such as MYRRHA will require important efforts also independent from operators.

The fast breeder economy will require more compact FBR vessels, 60 y operation material strength and a burn up of more than 3 times present values with considerable heat and activity impact for other phases of the fuel cycle.

The complex reprocessing technology was up to now a success story for AREVA in La Hague with limited dose to workers and the public end strictly controlled environmental releases, but with economic doubts even for EdF. The siting was selected rigorously for its dispersion capacity as well in the atmosphere as in the sea. However the bottle neck is the huge release of medium living (half time 10y) noble gasses such as Kr-85. Already now 50% of release limit is reached. Pollution is measured till Belgium and globally dispersed over the atmosphere with residual uncertainties for atmospheric interaction processes. Nuclear regulation up to now is not considering ecosystem impact yet. Local environmental problems occur occasionally in inversion weather conditions.

Very High Temperature Reactor
The concept of (very) High Temperature Reactor (VHTR) is different from the fast neutron concepts and was earlier developed and demonstrated in Germany, USA and S-Africa. This is a total energy concept with up to more than 70% efficiency instead of 33% for LWR electricity production. Process heat, production of hydrogen (chemo-thermal) and combined cycle (He) co-production enlarge perspectives for this kind of reactor system. This reactor can work as well with U as resource and carbide as fuel matrix as with a thorium fuel cycle. No Belgian research efforts were launched for this transition roadmap. However this concept of small scale of about 300 MWth could be inserted easily in our Belgian industrial tissue if safe integration of processes can be agreed.
This system is even considered by the EC as most inherently safe and could match much more than FBR the requirements of energetic sustainability and energy efficiency. The last aspect is not being considered for priority setting by EC. Moreover this concept could function with U but also with another resource, thorium, also abundant in the world. AREVA is investing now in the development of such a reactor having been demonstrated already before at small scale prototypes in the world (Germany, USA)
Technico strategic arguments regarding waste are discussed in a separate chapter below.

Belgian dynamics: MYRRHA[30] project

The MYRRHA (Hamid, 2010) proposal of SCK, started in 1998 and became a side roadmap of FBR development and related closed fuel cycle, which will be discussed here.
MYRRHA aims design, construction and operation of an accelerator driven, lead-bismuth cooled, sub-critical fast neutron reactor
The Venus zero power reactor in Mol was already transformed earlier in French collaboration (CEA) for preparing and supporting this shift in policy of SCK towards fast neutron research. The FBR policy was however opposed and halted 20 year ago on behalf of the government.

[30] Multi-purpose HYbrid Research Reactor for high-technology Applications

The move in nuclear policy of SCK happened after a new management took the lead supported by a new strategy of the board, replacing the consensus participatory approach of the former management.

Locally the new strategy for Venus was paradoxically not formally submitted to local participation during authorisation processes while for waste disposal projects, original participative approaches had been set up in Mol with successful results.

The move in policy was not submitted neither to a debate in parliament. This was postponed by numerous governments since the reprocessing was stopped (Laes, 2007).
At political level this presents now a strange situation surprising all international observers. A country with a phase out law and a clear political option of parliament for an open fuel cycle and MOx refusal is now authorising and financing a huge programme aiming the opposite and even taking the lead in French collaboration in Europe. This happens without parliamentary debate and public involvement. Only the federal council of science policy was giving a controversial recommendation directed by SCK without real assessment. It illustrates as in the financial sector the existential crisis of representative democracy where representatives of the State no longer represent the spectrum of views of at least half of the population on a societal challenge they all pay. It illustrates also the characterisation for research of public nuclear institutions, Prof W. Bijker[31], a technology assessment expert of Maastricht University had proposed as research question: the *unruly* nature of the nuclear sector in a democratic context. In the history of controversies the robust management boards and strong nuclear networks were already characterised as a state in the state but arrogance was also identified as a main weakness for long-term perception. It also illustrates how pro and con nuclear points of view are cross cutting in all political parties while not yielding the long term stability or minimum consensus this kind of decision making requires.

The MYRRHA project is framed clearly by the project leaders within these three reduced pragmatic sustainability criteria: better use of resources, waste minimisation and reduced proliferation risks. A side reference is made to climate challenges and electricity demand or supply growth perspectives, which are not necessarily sustainable as suggested in the SCK logo.
But MYRRHA is more than that. It aims to be a flexible fast neutron spectrum irradiation facility but it is also a very complex multi purpose machine intended for medical isotope production purposes as for replacing the BR2 material test reactor.
It is an ADS subcritical system but as well intended to operate as fast neutron critical system for burning MA with homogeneous (with U/Pu) or separated heterogeneous recycling of MA. The deployment requires significant and surrounding research mainly for advanced fuel cycles: new fuel matrix fabrication, advanced reprocessing and recycling technology, adapted for highly active hot fuels, new materials, simulation tools, fundamental nuclear data research (as done before under IIKW umbrella) and the coupling in case of ADS between accelerator (with its requirements for IBA) and sub-critical core or n multiplier. The feasibility of interesting transmutation perspectives of this project should be demonstrated.
The updated project schedule is announcing operation in 2022 but the decision of the ministry of Energy only approved yet the preliminary phase till 2014 starting the front end engineering design and which is budgeted for 60M€. A prudent DM approach was suggested by the NEA assessment report in 2009 as discussed below. This first phase should secure licensing, minimise technological risk and implement a sound management structure as well for the

[31] PISA, private communication

accelerator, the spallation target cooled by lead-bismuth and the EIA of the (sub-critical) reactor.
MYRRHA is a challenging scientific and technological adventure but also a huge technical economic risk with a number of challenges for safety, the environment (Po contamination) and proliferation. This is almost not yet addressed by the regulatory authorities in an independent way. The complex proliferation case was not yet worked out as subproject in detail by SCK. The safety criteria do not exist in a specific sense and need to be developed as well by research and (expensive) international networking. The whole project is mainly an enormous financial adventure now estimated at 1B € (40% Be). The cost structure is 20% building, 37% equipment and 20% engineering with 19% contingencies. The socio-economic perspectives for the region are real as operational costs are estimated at 60M€/y with as many revenues in the most optimistic hypothesis, but questionable for a country not having anymore a fuel cycle industry.
NEA has not evaluated this aspect.
Moreover the project occurs in a period of pressure on public finances and will depend of 60% support from abroad (EU, France, Germany, Italy, Spain, Japan, USA, and recently China, Korea, Emirates,..) with loans from the European Investment Bank. It creates challenges of liability and know-how management, which should consider painful lessons learned in Mol from past ambitions of the same nature and finally added to the public bill afterwards.

It was questioned during the NIRAS expert meeting e.g. by the author if MYRRHA is not confirming the transfer of DM on research strategies from Belgium to Paris as happened before for the financial and electricity sector.

NEA evaluation report of MYRRHA: MIRT

In view of the financial implications the Belgian government asked NEA to organise an independent international evaluation (MIRT) of the MYRRHA project and to advice on process steps. (NEA, 2009)
MYRRHA is considered to be able either to work as well in a subcritical as a critical mode. For NEA SCK intends to run the reactor as a critical fast neutron irradiation facility in a later phase of work, decoupling the accelerator (high energy protons) and removing the spallation loop from the reactor core. It is focussing then on Gen IV fuel research and becoming available for fundamental research (the so called strategic perennial aim of a large machine for SCK in region Kempen.
MIRT could not evaluate the regional economic impact of Myrrha estimated by SCK to generate approximately 5 B€ for the region Kempen.
The multi purpose goal is considered as very ambitious and could lead to a daunting accumulation of technical requirements. Alternative strategies for reducing project risk are suggested[32].
The exciting and attractive endeavour of Myrrha for SCK is recognised but could require another management approach in partnership with industry and universities in particular to build early a core competence in accelerator technology.
The budget estimations for MYRRHA are compared to the last large French project of the JHR in Cadarache (650 M €), much less complex than Myrrha, but having a lower capacity of 57MW vs. 100 MW in JHR. Budget seems reasonable except for contingencies which should be taken at 30-35 % for innovative projects at that stage.

[32] p16

The operational costs are considered as an underestimate (60 M €) compared to another large accelerator project in Grenoble; 10% of investment cost is more reasonable.
The schedule to full operation appears very optimistic regarding innovative complexity also in management.
The MOx fuel of 30-35% Pu is a critical issue and will depend on obtainability from Japan and politically delicate transports of Pu. The alternative of a 20% U-235 starter core could change the later performance. If large FBR development in France goes on up to 1500 MWth fuel delivery could be integrated in French manufacturing after 2020.
Also material licensing requirements could need long term commitments for a range of fuel options.
The construction and commissioning will be a massive task calling for the regulator to prescribe safety requirements where delays could be very important. A set of expectations for FANC is addressed by NEA. This could be a large task requiring a lot of investments and capacity building from the Agency (licensing procedure, hazard analysis, international harmonisation within Gen IV, past experience feedback on lead–bismuth, justification of design features). This should still be discussed by the expert regulatory advisory committee of FANC. NEA remarks that the skilled manpower for the safe management and regulation required for such a complex set of technologies is not readily available on the market.
NEA considers that the revenue streams, anticipated in the BUS plan, are not impossible to achieve if a number of countries opt for ADS driven P&T; it remarks that within the GIF or EC approach anyway a selection will be needed from 6 to less than 3 systems. If LFR (lead cooled fast reactors) will be retained, MYRRHA should be well placed but Russia with his large liquid heavy metal experience might wish to contribute in Gen IV. Moreover 60M€ is a theoretical maximum not taking into account capital costs.
NEA compares proliferation challenges of BR2 and MYRRHA, the latter being more proliferation resistant having less easily divertible MOx but a higher material throughput. The conclusion is rather optimistic but limited to the machine and not to the related (e.g. transport) processes.
NEA concludes that MYRRHA is unique in the world and could play a valuable role in future It could partially demonstrate the principle of transmutation by ADS fast neutrons. However it is not yet possible to see if P&T can add enough value in the disposal of nuclear waste to justify the additional costs incurred and whether such ADS systems would be necessary. Moreover It is not sure that LFR will retain preference at EU level.
MYRRHA is less well placed than JHR and Pallas for material testing while fundamental research will depends on unsure funding.
NEA notices that substantial risks remain: costs, financing and time could exceed estimations; performance will take longer.
The risk essentially remains on the Belgian government’s shoulders and a next stage of reflection and consolidation of collaboration is advised, before final decision making-. NEA suggests separating projects elements to decouple performance risks. The Belgian government should give the go ahead only for a further phase of work (detailed design, some R&D and other support, harder commitments, clarification of international interest).
The Belgian government could also abandon the project or go ahead with large and uncertain financial commitment for future.
In diplomatic terms this report is rather negative and calls for serious reflections.
It is noticed however that Belgian political DM in nuclear in particular has always been characterised by a lack of independent assessment culture. Moreover no authority has considered yet such projects in a holistic way taking sustainability criteria fully into account while the original objective is framed within sustainability.

Waste considerations regarding P&T in Belgium

MYRRHA was presented in public debates and political lobbying by the organisers as solving the long term waste issue, reducing nuclear waste to a problem of less than 1000 y. The research of the SCK waste department itself and the environmental reporting of SCK in MIRA (VMM) have clearly illustrated that only a reduction of long term waste will occur. This necessitates anyway a long term geological disposal programme for the non recycled U, Pu and minor actinides but in particular for the long living fission products created in reactor fuel, which are not eliminated at all.

The fission products create the decay heat in the first 150 y requiring cooling of about a century before disposal of high burn-up waste can be done in clay. Actinides too yield decay heat over 1000y which could be reduced by P&T and although reduce the surface of underground disposal.
The radiological risk over 1M y comes mainly from FP and activation products and therefore the long term geological disposal requirement remains. Potential dose is not created by actinides as they are well kept in clay with very low solubility.
Radio-toxicity is determined by actinides including the Pu spectra of radio-nuclides. This will only reduce not eliminate the risk of later intrusion in a disposal site (Marivoet, 2006).
Finally NIRAS is very clear in its Waste plan of 2010 stating that a long term geological solution for nuclear waste disposal will always be needed. Moreover the existing B&C waste categories can never been transmuted in the new concepts.

The major long living fission product (among others) in spent fuel is I-129 with more than 1M years half life time. The long living fission products will not be eliminated during partitioning projects in Gen IV and will continue to create anyway a necessity for long term waste disposal, whereas of smaller capacity. This will require contrary to present developments an international waste disposal solution in order to be economically affordable.

The refusal of France as driver of Gen IV fuel cycles to accept long-term nuclear waste from abroad even from French companies remains the major paradox in nuclear policy coherence and sustainable development.
France had recognised earlier in the nineties the impact on the environment of long living fission product such as iodine as a major concern but this is now regarding more as a philosophical concern of low level impact but over very long periods, also a trans-generational equity challenge by definition not take up seriously by the work of Taebi.
France started to apply environmental dilution of such long living by products by releasing a large fraction of them in sea and atmosphere in La Hague. The residual fraction, approximately half, belongs to the waste inventory to be disposed. But containment of more than 1M years is considered almost as impossible.
The comparison of risk made with radioactivity content of U resources as done by NIRAS and also by Taebi is only half a truth. It is based on controversial equivalent radioactivity since those fission products or actinides almost do not exist in nature neither in a concentrated way.
Taebi remarks that multiple recycling of spent fuel by advanced P&T methods are in development and that partitioning (reprocessing) could allow to separate also minor actinides (Np, Am & Cm). Transmutation could allow fast neutrons to destruct by irradiation and fission an important part of minor actinides. This should still be demonstrated and partitioning failed after one cycle in the past while the burning of Pu was almost blocked confronted with technical, cost and safety problems except in Russia and India. Taebi is not taking up historical and economical lessons from fuel cycle developments limiting his interesting

approach to one philosophic theoretical aspect of sustainability, part of the trans-generational equity problem.

VI.2. Clustered Factor analysis I ☹ P ☹ S ☹ E 😐 G ☹

VI.2.A Reactor Technology

The reactor technology priorities for Gen IV are chosen on a limited technology push basis within a exponential growth logic where spent fuel from Gen III will deliver fuel for Gen IV. They are not based on an equilibrated set of sustainability criteria.
The fast neutron reactors have no total energy concept due to limited temperature.
Safety challenges are real, increased burn up and material requirements still pose serious problems. The economy is uncertain with questionable history. Proliferation resistance from cradle to grave remains very challenging.
The only reactor technology (VHTR) with a promising energy efficiency combined with a fuel cycle diversity (U,Th) is only given secondary attention at EU level and marginal attention in Belgian R&D.
Considering delays in the past, the risk exists that these fast neutron technologies enter competition for centralised electricity production with fusion in the second half of this century, while the required budgets could not allow to continue such enormous combined efforts.
Decision making reintroduces the *fait accompli* and expert dominance without public debate and participation of involved actors. Siting occurs again on border sites.
The choice of Myrrha in Belgium has not seriously considered the relevance of alternatives such as HTR for the needs of the Belgian energy demand and industrial supply capacity and neither investigated siting limitations related to densely populated areas.

VI.2.B Fuel Cycle

Advanced fuel cycles aim at increasing resource efficiency. However it is not explained in a transparent way that this is only realised over a century through numerous cycles of consecutive spent fuel discharge, transport, reprocessing, fuel fabrication and reactor irradiation in which losses occur and secondary waste streams increase. The theoretical resource efficiency result of a factor 30-50 should be demonstrated and was very limited in the past. Moreover fuel abundance exists at the moment for at least 1 century .
The reduction of environmental releases is low and no programme integration is made for atmospheric challenges similar as greenhouse gases, in particular the radioactive noble gases where technology exists for reduction.
The waste reduction target is presented in a exaggerated way since long term geological waste disposal facilities will always been required for fission products and residual actinides. No progress is realised for waste management at continental level. The sub-economic solutions of individual states will become even more expensive.
Proliferation resistance of new complex fuel fabrication and reprocessing will require centralisation of fuel cycle industries limiting regional economic benefits and return.
An open question remains who should pay development cost of operations to decrease waste volumes from former and coming Gen III reactor operations.

INPRO provides an investigation of the U-233/Th fuel cycle, where Th is a fertile material that can be used to produce fissile material where even Pu could be used to start till sufficient creation of U233. It could potentially eliminate enrichment and makes the reprocessing more proliferation resistant or even not necessary (open cycle).

VI.2.C Drivers of development

Climate change is considered as main driver while indicating an internal contradiction for the nuclear sector, which is not using a ecosystem approach for its own atmospheric releases.
The improvement of Uranium resource efficiency illustrates the contradiction that a considerable growth in Gen II and III reactors was and is required to feed fuel for Gen IV "burner" reactors in order to correct their low resource efficiency in an extensive set of fuel cycle processes over a long time.
Technological optimism dominates the scene again as 45 years ago and technology push in multiple parallel forms overwhelms a demand oriented approach. Desalination and hydrogen show a revival of attention in this nuclear discourse. Electricity and gas demand forecasts and supply competition are important parameters of high relevance for defining the extent of programmes like Gen IV.
The EURATOM treaty has shown clearly its strengths and weaknesses for further development but cannot be changed within the political impasse in Europe.

VI.2.D Regulatory Aspects

There is progress in principles and regulatory collaboration in IAEA (soft law) and Europe, where more regulatory enforcement is possible with limited parliamentary control. The impact of the commission remains however low except in supply oriented developments as in the framework programme for Gen IV. Small attempts occur to correct for lacking harmonisation in regulatory requirement.
The challenge of depleted uranium and former mine remediation is not integrated in the approach.
A common waste management policy is seriously delayed while a common policy on nuclear liability remains on the long run together with the setting of distributive international guarantees such as for waste.
Proliferation being considered as main challenge for nuclear sustainability could be advanced not only in technological system design but also by some precaution in (financial) collaboration with countries with limited democratic traditions and with weapon states without commitment for disarmament.

VI.2.E Social Interaction

Public perception analysis shows a coupling of the solution of waste management to the attitude on nuclear energy development. Progressing with nuclear development and with controversial concepts of the past (fast neutron reactors) in a apparent sustainability image could create a boomerang effect when people will realise that the waste problem is not solved in the coming decennia. The Gen IV programmes require in their long time perspective political consensus as they will need large public budget and political stability over a long period. The lack of dialogue even of information on present programmes creates a democratic deficit which could endanger the **continuation** of options in future. There exists at the moment a complete different picture and expectation of nuclear renaissance within the nuclear sector and outside.

Qualitative Check of Sustainability Criteria for Gen IV

Integration (I)

Some aspects of sustainability are focussed (resource efficiency improvement, low carbon and reduced waste) to argue the old FR technology project in an advanced version including its fuel cycle. Energy efficiency (losses) and the matching of demand and supply is not yet a first concern in this for the nuclear sector. The approach remains far from coherent and can be considered as not realistic. The present economic crisis requires budgetary restrictions everywhere within the next years. This will increase the pressure on selectivity of public efforts addressing integration of investments in regional or national industrial tissue, but also the availability of expert capacity and the real social needs for large projects.
The regulatory approach in Belgium and EU is delayed considerably regarding integration of it in nuclear renaissance projects, such as the MYRRHA development. While this Belgian project for Gen IV is going to double the nuclear research budget there is almost no provision made yet to enforce in a proportional way the regulatory capacity in an international framework for safety criteria setting. The Federal Council of Science Policy failed to set up a real technology assessment capacity above the interested parties involved. NEA sent a relevant warning on project risks.
The Belgian choice of a side roadmap for fast neutron reactors is not energy demand oriented in Belgian society but seems driven by French fuel cycle industry interests. The fuel cycle objective had been interesting in case fuel cycle industry had remained available in the region of Mol which is no longer the case. The regional socio economic impact is not assessed independently neither is the sustainability of the project. (I-)

Precaution (P)
Precaution is almost completely missing in the sustainability concept of Gen IV in particular at EC level. The NEA report clearly indicates that the uncertainties related to the proposed Belgian project require a precautionary approach as well financially, as regarding technological and regulatory risks.
The radiation risks are far from negligible and the proliferation challenge is real. The regulatory advisory board has still to start its work.(P-)
But the options of Gen IV also have an important ambiguity where value judgements come into play Transparency on the perspectives of the project was not created regarding waste in particular.

Stakeholder involvement (S)
No public forum was organised to involve stakeholders for decision making on new fast neutron facilities for SCK in Mol as was set up by KBS and NIRAS for the National Waste Plan or earlier locally for LLW disposal projects in Mol (S-). Considering the de facto fundamental policy rupture regarding fast reactors and closed fuel cycles and the lack of parliamentary debate, it can be expected that nuclear controversy on Gen IV in Belgium will start at later strategic moments. The overlap with the controversy on Gen II phase out and with the Waste Plan is confusing but could amplify controversy. The social research of SCK had clearly indicated in the past the necessity of associating the public in due time to such projects of societal importance if possible in the research definition phase (as put forward also by the British parliament after the UK waste crisis). The social researchers of SCK also had argued such approach when criticising decision making on phase-out. The question, Anthony Blowers suggest in comparing different countries, is "do we meet the end of a participation experiment in nuclear for regaining the former decision making culture".
Local information was started but formal consultation on the authorisation of a related project was abandoned.(S-)

Equity (E)
Trans-generational equity can be argued for roadmaps as Gen IV but they are theoretical and make abstraction of historical indications as long as feasibility is not demonstrated. A coherent waste policy should first have been accepted and financially guaranteed for the ongoing century as argued by NIRAS. A Gen IV project is not solving waste issues of the past which are most relevant for the region of Kempen. The intra-generational equity has to be demonstrated first which was not yet the case and should be clarified at the moment of final decision on project choices compared to relevant alternatives. (E+-)
Blocked investment situations as "Lange Wapper" in Antwerp should be avoided. DM on such large future investments of local and regional importance with interventions of interest from abroad was based on expert views and enforced without fully considering distributive issues and involvement of relevant actors.

Global responsibility (G)

The French interests in Gen IV are clear for their core business as well in fuel cycle industry as reactor construction. But is this scale of the project realistic for a small country without nuclear industry anymore with a divided public opinion on nuclear? The drive of EC only takes a partial responsibility as each other contribution from abroad. Input in particular from large countries with a diversified portfolio should not be considered as a caution for Gen IV projects but be regarded on distributive issues and property protection, as learned from the past in industrial projects in and around Mol. The future of Gen IV will depend a lot on American decisions in future, on feasibility outcome from high risk research and on economic evolution in Europe. Few siting possibilities exist in Belgium for industrial projects in future. Industrial valorisation only exists in accelerator industry and foreign engineering companies. Which responsibility is taken up by EC for accompanying the required regulatory approaches of such projects in a small member state? (G-)
Is Belgian politics in existential crisis capable to assess, decide and regulate, with full responsibility for the common good, such complex case and that within the coming three years?

VII. Fusion (Generation V)

Fusion is also driven since the seventies by the technological desire for independency in energy. It is a successful global scientific collaboration overcoming (G+). ITER should provide a safe, clean and inexhaustible source of energy for the future.
Considering that the fusion project is only planning industrial deployment after 2070 only limited attention is given to this pathway in SEPIA.

Fusion of abundant resources of light materials under strict conditions is addressing cheap centralised electricity production with limited energetic integration capacity (I-), but requires still some high tech revolutions.
Light cores of tritium and deuterium, both isotopes of hydrogen can create energy through fusion at 100 M°C. Lithium (10^3y reserves) and water are abundant resources.
Fusion can compete with fission in risk for the environment and in accidental risk. Almost no long term nuclear waste is created (more than 1000 y management) while releases essentially concern the radionuclide with lowest radiotoxicity, tritium.

Fusion was tested for military purposes in the hydrogen bomb (I-).
ITER, the International Thermonuclear Experimental Reactor (the *way* in Latin) is the next stage or pathway element towards fusion. It is of 500MW fusion development machine (no net power production yet) with site selected at Cadarache (Fr). The project will cover half a century (conception started in 1988) but a next stage prototype machine will start to be build around 2035 in Japan. ITER building takes 10 years and exploitation 20 years. Recently first plasma was announced for 2019 with start of the deuterium-tritium operation in 2027.
A review paper on fusion states two sustainability criteria: no decrease of environmental quality in the long run and no decrease of well being in an alternative economic sense. Translated it should provide cheap and abundant energy, accessible and available in future and ecologically safe.

The ITER project in Cadarache started construction preparation but already met a considerable budget escalation of almost 50% due to complexity of global market organisation in such international projects (G-). Construction and exploitation cost about the same over 20 y. EC takes 40% in charge and France 20% while obtaining as host country the major part of industrial contracts. For Belgium AGORIA took efforts to join Belgian industry in a number of opportunities. SCK is still the major Belgian representative in international fusion research (E+-).

The EU budget had to be reviewed in 2010 from 2.7 B € initially to 6.6 B € for 2007-2020 but this could amount to 7.2 B€ (>15B€ in total), necessitating serious transfers of budget within EC framework programme. This was criticised by high level experts. Former Nobel price in physics the late Georges Charpak took the lead of scientists asking to halt the ITER project in an article in Libération on 10/8/2010. ITER penalises too much other more important research actions. ITER is out of price and “inutilisable”. Too many technological bottle necks need to be eliminated before being able to realise controlled nuclear fusion; they mention in particular the plasma containment requiring the discovery of new materials and the production of tritium in industrial quantities. The state of the art is far away from a prototype electrical machine. The scientists suggest to invest more in the Gen IV research.
There are also public concerns around Cadarache not so much on the environmental issues related mainly to containment of huge quantities of tritium. Public is concerned by the

transformation of the whole region through such a mega project which changes social structure through influx and transport infrastructures (E-).

Participation experiments using focus group technique were set up by PISA SCK. They noticed the lack of transparent information regarding such real daily public concerns (S-). Meanwhile some proposals were made by French project managers and by the Fusion Direction of EC in the Art 31 group to allow more tritium releases to the environment and to reconsider the notion “tritium incident”. A relaxation was even asked of the European drinking water directive for potential fusion releases in Cadarache (P-)
An appraisal of the nuclear waste implications should be made and checked on the requirements of the upcoming new directive on nuclear waste management of the EC (P-+).

VIII. Reflexive Conclusions

Nuclear controversy only started after demonstration of **global pollution** due to fall out of atomic bomb tests. (E)
Military misuse and threats had a negative influence on public perception. (P)
Not enough coherent attention was given by Belgian nuclear actors to these ethical concerns with perceived weight. It could be addressed in future by a more reticent attitude in new alliancies for business. Examples are new rich countries having poor democratic standards or leading nations which continue to develop atomic bombs.

When new reactor **sites** were looked for locally in the past, nuclear opposition became organised.
This should be considered now in due time for life time extension strategies of Gen II NPP's and other old nuclear facilities and certainly for Gen III proposals in order to organise dialogue before, instead of waiting for reaction on policy making by "fait accompli".
The lack of **siting policy** illustrates a **lack of coherence** as important indicator of integration, required by sustainability.(I)
Opposition was first successful in Belgium at the coast where the Zeebrugge site was abandoned. Opponents were driven either by religious values, either by redistributive equity views and/or by ecological values at embryo level. They got inspiration from critical scientists having little conflict of interests and although more public confidence.
It finally created the political foundations for phase out in almost all political parties.

The **accidental hazard** of NPP's was, contrary to scientific discourses, demonstrated to the public in **Harrisburg.** Human error was blamed too much but the strength of safety in depth concepts was demonstrated as well. The destructed NPP remained under control for external environmental releases. Notwithstanding it had a disastrous impact on nuclear investments for over 25y. Accidents with large societal impact such as in case of reactor vessel rupture are possible also in our neighbourhood with our protection measures. The probability is very low, more preventive technology is available for new Gen III plants but insurance provisions are still insufficient. (P)

The **Chernobyl accident** occurred 25 years ago in the middle of a controversy on fuel cycle transitions (FBR, MOx) and waste. It demonstrated the on-site destructive power together with a need for evacuation of a large region for a long period and illustrated as atomic bomb tests had already done the global pollution capacity of nuclear power. Accidents of global impact were considered before as almost impossible by experts loosing confidence afterwards. The causes were complex and not only related to Russian technological concepts, not criticised before, but also to political causes, management reliability and lack of criticism in engineer education. It mobilised less biased emergency management worldwide and improved the capacity to measure radioactivity and the modelling of its global dispersion. It was disastrous for the Soviet political system but also for the demonstration of incapacity of western authorities to manage environmental crisis and communication (I,G).

The public refusal of **sea dumping of nuclear waste** was long time underestimated but had to stop in the early eighties. A pure anthropocentric expert approach, guaranteeing marginal impact on human health due to the large ocean dilution capacity, had neglected effects on local ecosystems and was no longer tolerated. Incidents had not been communicated to the public. Afterwards SCK had problems in treating its waste. Technology was not mature as told. An international nuclear waste scandal occurred in Mol (TRANSNUKLEAR) from 1986 to 1992. The parliamentary enquiries and recommendations had a very negative impact on public opinion. But it allowed also to restructure nuclear R&D independently from waste management. NIRAS became fully operational and Nuclear Waste Management (NWM) started really. (I,P)

Crisis management transformed nuclear culture and had to abandon or decrease industrial financing and in particular to stop the exhausting European fast breeder collaboration (Kalkar, Superphenix). New priorities were set (safety, waste, integration of human & social sciences, medical applications and safety). It allowed **SCK.CEN** to survive as robust and qualitative public institution and to gain confidence again. The composition of the management board of SCK by political parties paradoxically never reflected the pro/con distribution of opinions in Belgian society. The transfer of non nuclear activities to the regional institution VITO has contributed to this aberration contrary to CEA which now has also the competence to develop renewables (I).

However global nuclear initiatives come up but seem to lack local and regional socioeconomic **distributive justice** arguments while claiming ecological and safety results. This contrasts with opponent views repeating local positions based on global arguments(E,S)

Nuclear regulatory approaches and the organisation of the State was delayed decennia. It had to take up responsibilities private companies can not share for long periods(nuclear waste. The crisis of the nuclear regulatory agency in Belgium, the delay at European level to realise a minimum safety and waste policy harmonisation, as well as the persisting ambiguity of proliferation policies worldwide, has revealed **contradictions in nuclear policy**,
Regulatory organisation has been given particular attention in the last three years considering its high importance for public confidence in managing risk complexity.
A number of corrections have been made through management optimisation but strategic corrections are limited and still constrained by political manipulation steered more subtle than before by interest groups.

Another major challenge, the management of **nuclear waste** is now presented systematically as technically feasible. Considerable integrated progress was made by the new management of NIRAS, being the first nuclear actor opening its DM processes for sustainability assessment structured in transparent risk governance initiatives. But the High Level waste problem is not yet technologically solved. Residual problems were demonstrated by the fundamental move in concept for geological disposal of HL nuclear waste in Boom clay at Mol. Moreover QC remains the Achilles heel in NWM.
Characterised as it is by a very long time scale a solution not only requires a regulation based on trans-generational values but also trans-boundary financial arrangements adapted to the globalised European market context of energy liberalisation. This was highlighted during the nuclear waste consensus forum of NIRAS/ONDRAF organised by the King Baudouin Foundation.
The nuclear debate is no longer a simple debate pro or con nuclear but became a debate on social distribution and justice. As put forward in the last MIRA report and as came up during the Public's Forum on the Waste Plan of NIRAS, the financing of nuclear waste management is not yet solved in this international context as long as the **EC** has not created common rules for international companies to **guarantee funding** over the borders and over long periods.

The **trans-generational impact** of nuclear waste disposal is now considered as a major challenge for acceptance, needing policy firmness and communication priority. (E,S)

The drivers of new research strategies on the contrary create the paradoxical image that new fuel cycle technology no longer requires long time management of nuclear waste. **Coherence** of all these arguments should be assessed independently with new methodologies.(I, E)
Similar participatory efforts as for waste disposal plans should be deployed for siting large scale Gen IV R&D projects.

All these **paradoxes** illustrate that a number of historical lessons could remain valid for prospective work. In such an evolutionary context of interests, new approaches of sustainability assessment of transitions can lead to a **coherency check of arguments** over the borders of the nuclear island (see also the contribution of J.Hugé).
Other demand/supply scenarios made in transition exercises of the Federal Planning Office and in EC Delphi Eurendel can broaden the scope beyond the so-called nuclear renaissance.

The **perception**, as an impression of risk reality, and the loss of public confidence as noticed in the late eighties and nineties have to be considered not simply as the result of a lack of information as the Nuclear Forum seems to assume. It is part of a social construct, historically grown and shaped by societal errors or culture defects of the nuclear industry and developers in the past (e.g. lack of coherent message and transparency) leading to loss of confidence. There is a serious risk now that the arrogance inherent to the nuclear culture gains momentum again within the hope and faith for nuclear renaissance. Nuclear industry could mobilise public institutions and political representatives to support a recent **communication** or **promotion campaign** (Nuclear Forum) in order to change or interpret the phase-out law. This occurs without installing the necessary research based process mechanism (RISCOM) to organise transparency claiming control as well on the truth, the authenticity as the legitimacy of the message.
Expert behaviour in nuclear has always been characterised by a defensive strive for conformity, interwoven with emotion above rationality. Some similarities with religious belief could be linked to the common drive willing to shape man and society in a world view.
Policy makers are really confronted with the lack of open minded experts without conflict of interests able to advise or to perform structured assessments.

The **phase-out** law of 2004, strongly opposed now by industry, can be considered in this whole context as a logic oscillation movement. It illustrates the noticed risk of poor success of integration of complex (nuclear) technology in society. Moreover we need to question simple reasoning pro or contra nuclear but to challenge policy makers if they are capable to learn from history in present decision making about phase out and regarding proposals for generation III and IV. A new pendulum movement in public opinion could be disastrous for nuclear renaissance as the period put forward by proposed investments concerns a century of transition roadmaps.

The international dynamics has added the new dimension of **globalisation** of a liberal market lacking however global regulation and adequate organisation of the common good.
At **European** nuclear level we still **lack sufficient regulation** (e.g. harmonised nuclear reactor safety criteria and control) and we lack policy coherence on environmental concepts between EURATOM and decision making- based on other treaties. A trans-boundary solution for nuclear waste is made almost impossible but will be a condition sine qua non for residual nuclear waste management in Gen IV, if realised.

The globalisation of main actors and the European liberalisation of electricity production, was unsuccessful in its market results. Monopolies in electricity remain capable to paralyse national political forces (citing the late EC Commissioner K.Van Miert in his last interview) Fundamental contradictions are illustrated in French nuclear policy with the refusal to accept nuclear waste from activities of French utilities abroad. The EPR crisis on the contrary confronts the largest nuclear actors in the world strategically with their inherent weaknesses regarding large scale new investments.

The application of present SD principles shows a poor qualitative balance of indicators.

The nuclear discourse has strategically taken up sustainability elements related to climate issues. The demand for more proactive assessment and precaution and for comparative **sustainability assessment** has shown to be a difficult task for the sector. Experts and institutions in the nuclear sector in particular face cultural difficulties with the transition towards sustainability. There is an absolute lack of independent expertise which is not particular for the nuclear sector. According to Anderson (2008), the evolution to expert partiality undermines the relevance of 'independent' decision-making processes.

It illustrates **lack of integration** of a technological sector in society. Paradoxically this contrasts with the robustness of the sector supported by international networks and still strongly financed by the government.
Precaution is almost not belonging to the culture of the nuclear sector notwithstanding important precursors such as ALARA in radiation protection and safety culture.
Equity is handicapped more than ever and requires international measures for nuclear waste and liability (insurances) recognising the trans-generational and trans-boundary nature of the challenges.
Stakeholder participation is on a turning point and should not be limited to blocked regional nuclear waste problem solving. They should be organised proactively as dialogue on future options conditioned by lessons learned from the past.
The **global responsibility**, once characterised by the strength and pro-activity of European nuclear policy (EURATOM treaty) is reduced to a conglomerate of national initiatives without global ambitions for common safety criteria and guaranteed waste funding and QC at EC level.

The international fora on alternative nuclear fuel cycles (Gen IV) present new generations of nuclear technology as sustainable contributions to climate challenge based on optimised resource use, long term waste reduction, proliferation resistance and safety improvements. But ecosystem approaches as for the atmosphere are paradoxically not yet applied within the nuclear sector. While mobilising huge innovation budgets for financing these future "sustainable" R&D strategies the EU was **unable to harmonise** waste and nuclear safety management and could not agree on a nuclear weapon-free zone in the Middle East, a *conditio sine qua non* for solving the proliferation challenge.

It can no longer been excluded that, considering the required huge budgets and time scales of development, internal competition even **controversy between the nuclear renaissance generations** will come up. A fine-tuning around Pu availability between Gen II/III and IV is inherent in coming decennia. Controversy started on the relevance of Gen V (fusion) after doubling of project costs of ITER in Cadarache. It was led by a Noble price winner (Charpak supporting Gen IV), as happened before in nuclear controversy.

To conclude, these considerations on all nuclear Generations, we remark that the financial crisis has shown that intergenerational trans-boundary ethics are still lacking within globalisation, while **conflicts of interests** still confuse politics at national level. The nuclear sector is technologically at least as complex and vulnerable as the financial sector and lack of transparency with bubble arguments were common to both. Nuclear also faces a trans-generational ethical challenge in NWM which has trans-boundary characteristics. Locally, non economic solutions are still to be set up institutionally. New participative initiatives are not yet formalised as demonstrated by the FANC approach for NIRAS proposals.

Are policy makers in there present existential crisis capable to learn lessons from the past and to manage or steer a complex topic as nuclear?

The answer in Belgium today is clear that even with the help of high level managers from the nuclear sector itself, such as in FANC, progress can be made but the political culture is such that only new transparency attempts or new accidents will be able to fully create conditions for success. Policy making at Belgian level is almost not capable to manage nuclear complexity at present and the European level is not allowed to act adequately yet.

The ethics as inherent and important element of SD should inspire future research options in nuclear and continue to change the **culture of nuclear experts** themselves to make possible high level independent assessments and finally f governance and decision making in nuclear as discussed.

Technology transitions as organised now for Gen IV should take into account inherent uncertainties and complexities and be framed no longer in an exponential electricity growth economy but in a **total energy concept perspective**.

SCK should be asked to consider in SIA the alternative of a more modest contribution to HTR development before final options are made on **MYRRHA** in 2014.
A minister of energy has never been warned so carefully by NEA in diplomatic language as done in MIRT but compensation policies have always been tempting in Belgian decision making culture.
A major challenge for Myrrha related decision making in the future is that no licensing base exists as was the case for reactors in the sixties.

A major sustainability challenge for long term operation of present NPP's as alternative for phase out is the vulnerability of Antwerp as economic mobility centre of Europe in case of accident.

The most important global sustainability challenge for nuclear energy remains proliferation, requiring coherence and integration at all levels.

Setting and controlling conditions for acceptance of new technological developments seems a never ending discovery where few lessons are learned.

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Annex 1:

SEPIA Process History WP4

1. Content technical annex WP 4 SEPIA

Nuclear energy is a thoroughly divisive issue in Belgian energy policy. Different opinions on the future of nuclear energy in Belgium notwithstanding, one cannot deny the fact that nuclear energy has marked energy system development in the past, and that energy systems in general show a great inertia towards changes. Therefore, in WP4, a critical assessment will be made of past, present and future nuclear energy policy options in Belgium in their international development context regarding strengths and weaknesses in the framework of sustainable development criteria. Attention will be given in particular to resource use efficiency, environmental pressure and health risk indicators, accidental risk, waste production, proliferation risk and acceptability and perception factors. The results of WP4 will serve as an input in the scientific debate on societal transformation towards sustainable energy supply systems, highlighting the role of assessment exercises in transition management.

The DPSIR framework will be used to make estimates on environmental, social and economic results and impacts. Lessons from past decision making will be drawn from the ViWTA nuclear controversy analysis (Laes et al., 2004) for present and future decision making in the new context of sustainability. The historical analysis essentially concerns reactors and fuel cycles of the first and second generation of nuclear energy development in Belgium, including the R&D costs. This will respond to the need to broaden sustainability assessments to incorporate the various dimensions of sustainability. Next to this, WP4 will consider siting criteria for nuclear installations in a densely populated region, and the long-term cost estimates and provisions for radioactive waste management and dismantling of nuclear installations.
For the present decision making in the context of European liberalization of energy markets and national attempts to phase nuclear energy, EPR (third generation) options will be scrutinized (taking into account the ongoing Finnish experience and the reasons for delay) situating siting and regulatory constraints in Belgium as well as some social impacts (in particular employment effects projected in the Belgian industrial context).
For the future, the long term fusion option as well as the generation IV US/European set of recent nuclear developments (including options such as partitioning & transmutation) will be considered qualitatively in the time horizon of 2030 (medium) to 2100 (long-term), using (amongst other references) the European energy Delphi exercise (EurenDel, 2003), and taking into account fuel cycle time horizons and new proliferation challenges. Particular attention will be given to new risks, such as terrorism while also looking at social challenges of centralized electricity production options compared to total energy concepts using small-scale high temperature reactors (which are marginally financed in comparison to the centralized electricity production development options in Belgium). This could allow to associate the qualitative nuclear case study developed in WP4 to possible perspectives of the hydrogen economy (cf. WP2 – Task 2.2). A qualitative nuclear report of 30 p as output will be generated in order to allow the application of sustainability in WP2 to nuclear energy at the same level of depth as other energy supply options. Moreover nuclear consult and support will be given to the researchers in other WP's in particular in participative exercises when needed.

2. Intermediate specifications for the Case study of Belgian Nuclear Energy Policy[33]

The contractual report of mid 2008 specified:

SEPIA WP4 will consider the Belgian 'nuclear pathways' – past practices, present political instabilities and future prospects of the nuclear energy sector – from the sustainability point of view.

[33] adapted after discussion with E. Laes, F. Maes and Jean Hugé with slight actualisations

The five basic principles of sustainable development will be used to qualify nuclear energy pathways in the SEPIA scenarios. The principles are: integrated approach (I), precautionary approach(P), stakeholder participation(S), inter- and intra-generational equity(E) and global outlook(G)
The analysis will be attentive to the cultural behaviour and discourse of the nuclear sector, as well as the approach at regulatory level and its consistency and transparency within the frame of this new paradigm. In particular, WP4 will address the possible ***confusion*** *between the "nuclear island" policy approach of EURATOM and the different environmental policy objectives for* ***moving towards sustainability*** *in a coherent way.*

The aim of the WP and a major research question is: ***how to clarify the challenges for the nuclear sector to meet the requirements for sustainability?*** It includes an assessment of the impact of demand-side strategies (included in the SEPIA scenarios) for possible nuclear roadmaps and refers to the exercise of the Federal Planning Office. Considerations on the integrated value tree analysis and on the applicability of indicators as developed in a *DPSIR* framework for the nuclear sector will be formulated as well. The relevance and coherence of results of some international research networks will be discussed. Some were set up to clarify and control uncertainties, distributive issues or global challenges (ExternE, Precautionary analysis, Funding provisions, Proliferation assessment).
An additional but related **research question** is if and how the long term vulnerability and robustness of the nuclear sector (both in technical and social terms) and related policy options could eventually be improved for acceptability in the long run. **Can the nuclear sector (with all its inherent complexities) be 'shaped' by the requirements of democratic functioning,** confronted as it is by a 'existential crisis'?
Attention will therefore be given to **fundamental paradoxes** facing the nuclear sector in its quest for sustainable development.

3. VUB proposal of May 2009 reframing the task

The nuclear energy evolution in Belgium and abroad of the last years is reported and summarised as well for fission as for fusion.
From historical perspective (40y controversy analysis, phase out dynamics) the implication of the Gen I,II&III reactor strategies (e.g. SG replacement Doel 1 and new fuel management cycles in the 7 Belgian reactors, Finland EPR delay, French EPR DM Flamanville & Penly and new UK reactor strategy at our border in Dover) is studied.
These elements are discussed in their implication for Belgian electricity supply and within some new environmental challenges in the context of sustainability for the next 20 to 40 years. Particular attention is given to the new dynamics in releases to the environment, nuclear waste disposal process progress (Dessel licensing by FANC for low level waste and NIRAS SEA process for high level waste) and the insurance problem of required financial state guarantees.
The GENIV evolution and the impact for Belgium is evaluated within the horizon 2050-2100. Particular attention is given tot the relative level of waste reduction potential in time perspective. The eventual competition with fusion regarding the required high development investments is looked for. The feasibility of the SCK Myrrha project is considered in present societal crisis conditions, European industrial dynamics and the new Obama directions in the USA.
Finally financial and regulatory challenges for nuclear energy are discussed within the new European electricity market evolution. Particular importance is given to distributive justice aspects of assumed transgenerational transfer responsibilities of international electricity producers acting in Belgium.

In addition a VUB proposal of Jean Hugé and Tom Waas to give methodological support to the non nuclear part of SEPIA, including reflexions on present nuclear assessments was agreed by the Coordinator. A working paper on 'Decision-support through impact assessment for energy options – reflections and practical experiences' was made as deliverable (**see Annex 2**).

The sustainability assessment (SA) as put forward by authors Pope, Morrisson-Saunders and Gibson is discussed in the additional input from VUB. It takes into account diagnostic-, explanatory- and orientation-knowledge as a base for evaluation of energy policies in the future scenarios and pays attention to the quality criteria; accessibility, adequacy and legitimacy account. It could yield further inspiration for the application of methodologies developed in SEPIA, while clarifying the scope of nuclear elements in scenarios.

When developing scenarios for the long-term development of the Belgian energy system, a range of impact assessment methodologies can provide the required information to structure the transition management process. While sustainability assessment defines the overarching structure underpinning the SEPIA project, this instrument did not pop up in an empty institutional environment. Decision-supporting tools such as strategic environmental assessment (SEA) and environmental impact assessment (EIA) are already widely applied in the energy sector at large (e.g. with regard to the creation of (off shore) wind-parks or with regard to the storage of radioactive waste). While today's society's energy sustainability challenges cannot adequately be resolved with incremental and case-specific approaches alone, the linkages between the full picture -as drawn by a sustainability assessment exercise- and the stepwise implementation of a new energy landscape will be clarified. An analysis of the function and use of various decision-making tools in designing sustainable energy futures will be provided. This work package will build on both international experiences and on Belgian cases.

4. Nuclear Progress Report Steering Group 15/9/2009

A first non-exhaustive and partial report of 17p was presented tot the steering group on September 15, 2009 in order to integrate remarks in the draft report planned to be presented to the project team for review mid august 2010.
It was based on input from own publications and co-edited books (Nuclear history (Laes, 2007), Ethics in radiation protection, Nuclear terrorism, Environmental report Flanders, Prudent precaution), on literature and press follow-up, and on participation to conferences (EC FISA, Prague, June 2009; RRFM, IAEA, Vienna, march 2009, AGORIA conference on Fusion, Groot Bijgaarden, 2008; different BNS(ENS) and BVS (IRPA) meetings and lectures, NIRAS conferences on HLW).
Input was also based on consultancy of involved scientists and of industrial actors and participation to meetings of the Belgian regulatory advisory board, the Health Council and the EURATOM art 31 advisory board for radiation protection.

Since then, this follow-up was continued and feedback integrated. Finalisation for internal and external review was agreed for September 2010.

Annex 2:

VUB Working Paper:

Decision Support Through Impact Assessment for Energy Issues – reflections and practical experiences

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Abstract

As energy issues are at the top of the policy agenda worldwide, policy-makers increasingly need decision-supporting processes to assist them in fostering a sustainable energy future. This paper reflects on the interpretation of sustainable development, and links these reflections with the theory and practice of impact assessment. An illustrative overview of impact assessment exercises in support of energy-related decisions leads us to advocate sustainability assessment, as this approach explicitly aims at realizing sustainability objectives.
Through a case study on a participatory sustainability assessment in support of the development of a radioactive waste management plan in Belgium, a literature-based discussion on the interpretational limits of sustainable development in a nuclear energy context is presented. This paper aims at presenting the complex context in which impact assessment exercises are to contribute to sustainable energy development.

1. Introduction

Today's world faces a series of multidimensional societal challenges. The environmental crisis is threatening human societies, and urgent actions are required to take on challenges like declining resources, demographic pressure and human-induced climate change. Energy plays a central role in many of today's crises, be it directly (such as through the emission of greenhouse gases) or indirectly (such as through the global geopolitical battle for influence). Badly managed energy issues can potentially lead to social disruption and to a further aggravation of the environmental state of the planet. Recent events with planetary consequences such as the Iraq War, the highest oil prices on record, the ever better documented consequences of rapid anthropogenic climate change (IPCC, 2009), the oil spill in the Gulf of Mexico and the emerging economies' increasing energy needs, have exacerbated the need for a shift towards 'sustainable' energy production and consumption. In its World Energy Outlook 2009, the International Energy Agency's states that the continuation of current energy trends would have profound implications for environmental protection, energy security and economic development, as well as dire consequences for climate change. This would also exacerbate ambient air quality concerns and cause serious public health and environmental effects, particularly in developing countries. In summary, the 2009 World Energy Outlook explicitly explains why our current energy pathway is unsustainable (IEA, 2008).

This paper deals with impact assessment, understood as a tool to evaluate, foster and implement sustainable energy-related decisions. Impact assessment is a generic term entailing a series of instruments and processes. The IAIA (2009) defines impact assessment as *'the process of identifying future consequences of a current or proposed action'*. The original idea of impact assessment is that the identification of potential future impacts will lead to better decisions, through the timely integration of the gathered information into the design of (public) interventions. In this paper, we introduce a principle-based interpretation of sustainable development and subsequently link it to impact assessment. This approach will shed light on the potential contribution of impact assessment to sustainable energy development, both in terms of interpretation and in terms of implementation.

If we are to reflect on the design and on the application of impact assessment for sustainable energy we require insight into three key issues:

- the conceptualisation of sustainable development and sustainable energy;
- the conceptualisation of impact assessment;
- the practical application of impact assessment for sustainable energy issues.

2. Sustainable development: concept and strategy

Sustainable development

The concept of 'sustainable development' was launched in the early 1980s (IUCN *et al.*, 1980) to reconcile the imperatives of development and environmental protection and is considered as an adequate answer to tackle the abovementioned challenges. Nevertheless, the concept is often misused or trivialized. A brief clarification of its definition is thus necessary. The most famous definition stems from the influential Brundtland Report 'Our Common Future': '*sustainable development is development that meets the needs of the present without compromising the abilities of future generations to meet their own needs*' (WCED, 1987). This often quoted sentence is actually the 'mission statement' of the Report, which points out that sustainable development contains two key concepts: the concept of 'needs', in particular the essential needs of the world's poor, to which overriding priority should be given; and the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs (WCED, 1987). Sustainable development is also a process of change, it is not a fixed state of harmony nor a defined end-state, as society, the environment and their interactions are subject to a continuous flow of change. Sustainable development involves a transition towards a dynamic equilibrium. WCED (1987) states that it is: '*..a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations'*. Consequently, the critique on conventional ('business as usual') thinking (and practice) is inherent in the concept.

Sustainable development's intuitive appeal to the 'common sense' of humankind – as well as its constructive ambiguity (Robinson, 2004)- meant that policy-makers and civil society organisations all over the world soon jumped on the train of sustainable development and made it one of the most often cited concepts in current politics. At the 1992 United Nations Conference on Environment and Development, sustainable development was formally politically endorsed through the adoption of the Rio Declaration and Agenda 21. The 2002 World Summit on Sustainable Development reaffirmed the world's commitment ten years later. More recently, influential scientific reports such as the Millennium Ecosystem Assessment (2005), the Stern Review (Stern, 2007) and the work of the Intergovernmental Panel on Climate Change (IPCC, 2007) exerted a major impact on decision-makers and all strongly reflected the sustainability agenda. Sustainability has thus gained rapid acceptance amongst political leaders, but in reality, this was -and still is- mainly visible in the lip service paid to it. Sustainable development is still too often interpreted as a vague and fuzzy concept, and although this might –somehow paradoxically- explain its popularity in becoming a guiding principle in day-to-day political decision-making, it did not lead to a satisfactory implementation of its core principles. It seems that (part of) the discourse is pervading every policy makers' declaration, but it is as if the implementation of sustainable development remains in its infancy almost indefinitely.

In order to structure the definition of sustainable development in more detail and in order to turn it into a strategic approach to support decision-making, we present a list of five key principles embodying the concept, as proposed by the Belgian Federal Planning Bureau (Federaal Planbureau, 2007) and as entailed in Gasparatos' *et al.* (2005) 'criteria for holism'. This choice is not absolute, as authors such as Gibson (2005) have proposed or emphasised different principles, yet it ensures the use of a coherent set of principles in the SEPIA research project. A principle is here defined as a rule of action towards sustainable development. This principles-based framework is by no means exhaustive, but we believe it to contribute to a better understanding of sustainable development as a concept and as a strategy.

- *Global responsibility* as a guiding principle is closely linked to the key contextual elements of the world-wide scale that defines actions towards sustainable development. The concepts of burden sharing and equity are embedded into this principle. The European Union holds a special responsibility in this respect, and promotes a sustainable development approach on a global level, as stated in the 2009 Review of the European Union Strategy for Sustainable Development (EC, 2009d).
- *Integration* is understood as the commitment to achieve the simultaneous and mutually reinforcing implementation of ecological, social, economic –and other- objectives of sustainable development. Integration also refers to the need to turn sustainable development into a cross cutting principle embedded in every future decision and consequent actions. Robinson (2004) synthesises by stating that sustainable development should reconcile development and environmental objectives, views and interests of different stakeholders, and various temporal and spatial scales. An interdisciplinary approach is needed to guide the implementation of sustainable development. It refers to the use of approaches from multiple fields of knowledge in order to get a comprehensive understanding of a particular issue..
- *Equity* is a central value of sustainable development. Haughton (1999) distinguishes inter- and intra-generational equity, geographical, procedural and inter-species equity. The basic idea that human societies should continue their quest for a better life is acknowledged in the sustainable development concept, but this should be done in a manner that reconciles different interests and considerations: economy and environment, conservation and progress, efficiency and equity, and the preoccupations of North and South (Lafferty & Meadowcroft, 2000). Re-distribution of global burdens and advantages is a key issue in this respect. Gosseries (2008) reflects on theories of justice to clarify the concept of intergenerational equity.
- *Precaution:* the precautionary principle, embedded in the Rio Declaration on integrating environment and development, states that 'the lack of full scientific certainty shall not be used as a reason for postponing cost-effective (..) measures to prevent environmental degradation'. More generally, three core elements are intertwined in the conceptualisation of precaution: uncertainty, risks and the complexity of the factors defining both uncertainty and risks. The Health Council of the Netherlands (2008) describes the precautionary principle as 'a strategy to deal with uncertainties in an alert, informed, rational and transparent and situation-adapted way'. Thus the precautionary principle can

be linked to sustainable development's appeal to 'common sense'. Complexity applies to systems showing deep uncertainties and a plurality of legitimate perspectives. Studying sustainable development entails non-linear causal networks, emerging issues and an awareness of limitations in understanding.

- *Participation* refers to the involvement of all concerned stakeholders in decision-making. In principle, it enhances transparency, communication and problem solving, by allowing the confrontation and contribution of various views. Participation aims at including the normative dimensions of sustainable development into decision-making. Normativity refers to the value-laden character of the concept of sustainable development. There is no absolute truth regarding its definition -although interpretational limits should be respected (Lele, 1991)- but this does not preclude us from acting towards it. Simply, the constantly evolving debate and discussion should be acknowledged. Normativity acknowledges the existence of alternative approaches to framing an issue. As Robinson (2004) states: science is crucial for sustainable development but it cannot resolve the basic question of what is sustainable and what is not on its own. Scientific knowledge is essential, but is not able to provide every answer to unknown future possibilities. Furthermore, there is a battle of influence over sustainability's meaning and the appropriate way to achieve it. Societal stakeholders seek domination over the meaning of sustainable development, trying to mould it in favour of their interests and view (Hajer, 1995), an observation that further justifies a participatory approach.
  Involving external (non-state) stakeholders into (public) decision-making through participatory exercises is inherent in the concept of governance, as defined by Petschow *et al.* (2005). Alternative framings of sustainable development and the associated alternative solutions are indeed key factors of if governance mechanisms are to foster sustainable development.

Sustainable development as a decision-guiding strategy

If sustainable development is to be a useful concept, we believe it should be a strategy, defined as a way forward to make happen a desired future, *in casu* the achievement of sustainability objectives (part 2). This desired future takes place within a particular context, defined here by sustainability's dimensions and elements described in part 1. The sustainability principles are the guiding rules of action to realize the strategy, while decision-supporting instruments such as impact assessments are tools to achieve that desired future.
Within this framework, the ultimate choices are in hand of the policy-makers, who will need to decide upon solutions for the many societal challenges we face today.

As one moves from the conceptualisation of sustainable development to sustainable development as a political reality, we agree with *e.g.* Lafferty & Meadowcroft (2000) that the observed discursive and practical behaviour of political leaders should contribute to interpret sustainable development in accordance with the particular context. However, this should happen without losing sight of the abovementioned key contextual elements, objectives and principles. Indeed, when decision-makers have agreed to undertake something called 'sustainable development', the interest is in seeing what this actually implies, but one must acknowledge the defining context, objectives and principles of the concept to avoid talking in the void.

3. Sustainable energy

3.1 Energy at the top of the policy agenda

The issue of sustainable energy production and consumption is now on top of the political agenda in many jurisdictions. In the European Union, policy documents such as directives promoting energy efficiency and the use of renewable energy sources, directives implementing greenhouse gas mitigation and atmospheric pollution reduction policies are key examples (Streimikiene & Sivickas, 2008). The overarching European 20-20-20 strategy (see section 1) turns sustainable energy production and consumption into tangible policy objectives, while the European Strategic Energy Technology (SET) Plan (EC, 2009) aims at accelerating the development and deployment of cost-effective low-carbon technologies and as such forms the technology pillar of the EU's energy and climate policy package.
The European Strategy for Sustainable Development also entails an important energy chapter. In July 2009 the Commission adopted the 2009 Review of the European Sustainable Development Strategy. It underlines that in recent years the EU has mainstreamed sustainable development into a broad range of its policies. In particular, the EU has taken the lead in the fight against climate change and the promotion of a low-carbon economy.
At the same time, unsustainable trends persist in many areas and the efforts need to be intensified (European Commission, 2009). Lior (2010) points to the severity of the challenges ahead: '*to prevent disastrous global consequences, it would increasingly be impossible to engage in large scale energy-related activities without ensuring their sustainability'*. The question then is twofold: i. how can sustainable energy be defined? and ii. how do we ensure sustainable energy development?

3.2 Sustainable energy

In order to further ease the interpretation and subsequent implementation of sustainable development, the term 'sustainable' has been added to sectors or issues such as 'sustainable' agriculture, 'sustainable' fisheries and off course 'sustainable' energy.
This led to the blossoming of a series of interesting and more tangible sub-definitions of sustainable development, but care should always be taken not to fall into reductionism, which would indeed undermine the holistic nature of the concept. The International Energy Agency defines sustainable energy as a balance to be found between the three E's – energy security, economic development and environmental protection (IEA, 2010).
The European Union outlined its vision on sustainable energy in the 2006 Green Paper on Energy, where the European Commission asks the Member States to do everything in their power to implement a European energy policy built on three core objectives: i. sustainability (to actively combat climate change by promoting renewable energy sources and energy efficiency), ii. competitiveness (to improve the efficiency of the European energy network by creating a truly competitive internal energy market) and iii. security of supply (to better coordinate the EU's supply of and demand for energy within an international context). In March 2007 the EU's leaders endorsed an integrated approach to climate and energy policy. They committed Europe to transforming itself into a highly energy-efficient, low carbon economy. To kick-start this process, the EU Heads of State and Government set a series of demanding climate and energy targets to be met by 2020. These are: a reduction in EU greenhouse gas emissions of at least 20% below 1990 levels; a target of 20% of EU energy consumption to come from renewable resources and a 20% reduction in primary energy use compared with projected levels, to be achieved by improving energy efficiency. Collectively these are known as the 20-20-20 targets (EC, 2010).
While the interpretations of sustainable energy held by major international organizations are of key importance, scientists have also presented some definitions: Verbruggen (1997) emphasizes the need for sustainability throughout energy generation, transmission and distribution and lists five key aspects of 'sustainable energy': conservation of energy; priority to renewables; reduction of negative environmental impacts; low vulnerability of energy systems; no threats to international security. Saha (2003) lists a number of options that should be followed for a sustainable energy future: widening access of energy services to the disadvantaged populations;

raising the share of low-carbon energy, in particular renewable energy, resources in the energy mix; energy efficiency policies; appropriate market and structural reform and a rational pricing policy; facilitation and financing of technology transfer; and international cooperation. Midilli *et al.* (2006) speak about 'green energy' as a key component of sustainable development and list three main aspects of it: low environmental impact; the reliable supply of renewables; increased decentralization and local solutions and hence increasing flexibility of responses.
While these definitions certainly contribute to a better understanding of what sustainable energy might mean in practice, the general principles set out above have the merit to set interpretational limits to sustainable development. They act as a guidance to remind us of the main issues at stake.

4. Decision-support for sustainable development through impact assessment

4.1 Impact Assessment: concept and functions

The International Association for Impact Assessment (IAIA, 2009) defines impact assessment as '*the process of identifying the future consequences of a current or proposed action*'. It is a generic term encompassing different instruments, approaches and processes, some of which are well known and widely used (Environmental Impact Assessment (EIA), Strategic Environmental Assessment (SEA), Health Impact Assessment (HIA), Regulatory Impact Assessment (RIA), Risk Assessment (RA), Sustainability Assessment (SA)), while others are more recent or specialized and often less well-known (Child Impact Assessment, Mobility Impact Assessment, Biodiversity Impact Assessment *etc.*). Impact assessment is assigned different functions in the decision-making process depending on the context where it is used. An analysis of the scientific literature leads to a proposed categorisation of *discourses* with regard to impact assessment.

First of all, impact assessment is presented as a tool/process to generate information for decision-makers to ensure that a decision is taken with the best available 'knowledge' of its (unintentional) impacts. Ideally, this guarantees that the best policy option is chosen. 'Best' is to be defined according to the objectives of the assessment exercise and may thus refer to the 'most environmentally friendly option' (in case of EIA or SEA), 'the best option with regard to public health implications' (in case of HIA), *etc.* Impact assessment is seen as an objectifying instrument supporting decision-makers. Impact assessment provides 'instrumental' knowledge, directly underpinning concrete decisions. This perspective supposes a rational approach to decision-making, and is known as the information discourse. But empirical evidence supporting this discourse is not always as convincing.

Instead, Hertin *et al.* (2008) see policy-making as a 'mess', undergoing influences from various categories of actors, all being subject to power struggles and strategic as well as coincidental considerations. Hence, simply fitting impact assessment in a rational policy cycle-model as presented in the information discourse is not a truthful reflection of reality. This second discourse does not consider impact assessment as a mere information-generating instrument. Here, impact assessment exercises provide a forum for debate and deliberation (Baber, 2004). The sustainability discussions carried out during a sustainability assessment hence contribute to a shared understanding of sustainable development in a particular context, through exchange and interaction amongst participants. This pre-decision deliberations enrich the decision-making process and lead to new perspectives, although there is risk of manipulation by partial experts, lobbyists or stakeholders' personal agendas. Impact assessment can thus be 'used' politically, to steer the decision in a particular direction or to justify decisions that would have been taken anyway. This second discourse stresses the political use (and abuse) of impact assessments in decision-making, as well as the deliberative forum function.

A third discourse stresses the decision makers' shifts in attitude thanks to the use of impact assessment. New knowledge provides the decision-makers with new insights and perspectives, creating opportunities for policy change. This is an illustration of Bekker's *et al.* (2004) incremental learning model, where the exposure to new knowledge leads to a gradual enlightenment of the decision-makers. This view emphasises learning effects as worded by Nooteboom (2007): '*The effect of an (impact) assessment procedure may well be that it will mainly benefit future decisions, while having a more limited impact on the decisions which the impact assessment was meant to inform and influence'*.

The fourth and most important impact assessment discourse emphasises the 'structuring power' of impact assessment. Decision-makers face many challenges when designing new policy. A first key challenge concerns the complexity of the issues at hand. First of all, the intrinsic complexity of multidimensional societal challenges is creating an ever-growing need for information and debate (Funtowicz *et al.*, 1999). Secondly, the institutional complexity arising from the new realities of multilevel governance networks blurs the boundaries between the responsibilities and competences of 'classical' jurisdictional entities such as the nation-state, and new players such as regions, stakeholder groups and multilateral organisations. The rise of 'governance', as opposed to the state's monopoly in decision-making - embodied by the term 'government' – is, although often welcomed, indeed a challenge for policy-makers. Governance, defined by Petschow (2002) as '*the sum of many ways in which individuals and institutions manage their common affairs'*, always involves some forms of co-operation between official government institutions and external partners such as the general public, businesses and/or civil society organisations. The rise of governance for sustainable development originates both in the global trend towards liberalisation and in the increasing complexity of far-reaching policy decisions.
These new challenges create a need for instruments to *structure* both the increasing intrinsic complexity and the institutional complexity of current decision-making. Impact assessment provides a systematic approach that allows policy-makers to deal with complexity and to structure the input of various actor categories. When integrated into decision-making, impact assessment becomes part of the process of developing new policy. The appeal of impact assessment lies in its easily understood basic steps and in its contribution to generate order out of the chaos by identifying linkages in complex policy-making environments. However, as Zaccai (2002) rightly states, impact assessments are based on a large number of choices (Which impact categories are considered? Which parameters are used to assess these impacts? How are these parameters being calculated and assessed?). This means that the results of various impact assessments applied on a similar case can still vary greatly.

4.2 Impact assessment for sustainable development: a principles-based reflection

While impact assessment can have various functions in what is broadly defined as 'the decision-making process', its design and application rest on a number of key principles. Three of these principles are discussed here, as they are directly linked to the principles of sustainable development outlined above.

4.2.1 Global responsibility

Especially in impact assessments for sustainable development (or sustainability assessments), the global dimension of impacts is usually taken into account. The rise of inherently trans-boundary societal challenges (such as climate change and its consequences) further emphasized this. The institutional translation of this situation is illustrated -among others- by the 1991 Espoo Convention on Environmental Impact Assessment in a Trans-boundary Context (UNECE, 2010).

4.2.2. Integration

The various meanings of integration in an impact assessment context have been studied by Scrase & Sheate (2002). These authors identify 14 meanings of integration. In summary, we propose to keep the following four key 'integration meanings' into account.
Impact assessments for sustainable development are to integrate economic, environmental, social and increasingly institutional issues as well as to consider their interdependencies (Gasparatos *et al.,* 2005). Next to the integration of the dimensions of sustainability, impact assessments are to integrate natural sciences and social sciences, as well as quantitative and qualitative data. Indeed, in order to inform decision-makers about future consequences of their planned actions, as many data (*sensu lato*) as possible are needed. A third meaning refers to the integration of stakeholders in impact assessment. A fourth meaning refers to the integration of impact assessment and its results into the decision-making process. Every type of integration aims at achieving different learning effects, and as such, all these meanings converge towards fostering a societal transition towards sustainability.

4.2.3 Equity

Equity as a sustainable development principle often manifests itself by way of the interpretations of intra- and inter-generational equity laid out in the Rio Principles. Furthermore, equity is explicitly taken up into thematic impact assessments such as health impact assessment (Simpson *et al.*, 2005).

4.2.4 Precaution

Some sustainable development principles (see section 2) are directly linked to the field of impact assessment. We've seen that the precautionary principle states that if an action or policy might cause severe or irreversible harm to the public or to the environment, the burden of proof falls on those who advocate taking the action, in the absence of a scientific consensus that harm would not ensue. The World Conference on Environment and Development defined the precautionary principle as a safeguard against potential risks. These risks would be determined from –environmental- impact studies to be undertaken in the planning phase of an investment. This view is embodied in the principles 15 and 17 of the Rio Declaration.

Principle 15: In order to protect the environment, the precautionary approach should be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing cost-effective and feasible measures to prevent environmental degradation.

Principle 17: The environmental impact assessment as an international instrument shall be undertaken for proposed activities that may have adverse impact on the environment, and are subject to a decision of the competent national authority.

Although the precautionary principle gained international recognition, it is still not widely applied when energy-related decisions are taken, despite its logical interpretation as representing 'an increased responsibility in precaution facing risks' (Zaccaï, 2002). De Carvalho *et al.* (2010) identify barriers to the principle's adoption stemming from the intrinsic logic governing the world's economic system, driving the energy choices by economic surplus and rent generation potential, the existence of global asymmetries as well as from the absence of democratic global governance mechanisms. The precautionary principle is a strategy to deal with uncertainties in a transparent, responsible, reasonable and situation-adapted way, and as such it forms an essential part of sustainable development as a strategy to make a desired future happen. Impact assessments should be guided by the precautionary principle as they are inherently characterised by uncertainty. This is especially the case in the face of four criteria: severity of the impact; lack of scientific knowledge; socio-political ambiguity (entailing individual, institutional, amplifying and social 'filters') and complexity (Zaccaï, 2002).

4.2.5 Participation

The increasing reliance of impact assessments on participatory generated knowledge is explained by a number of reasons. First of all, participation is key in realizing a shared understanding of sustainable development and/or sustainable energy in a particular context. Indeed, sustainable development challenges mere scientific rationality, although its interpretation is off course constrained by certain interpretational limits. Sustainable development does not mean exactly the same to anyone, and this realization is a key premise, whether one likes this or not. In order to operationalize the interpretation of sustainability that is held to be valid in a given context, subjectively derived characteristics of sustainability are useful if subjectivity is explicitly accepted and declared at the outset and if the method for deriving the measures is available to a range of stakeholders (Bell & Morse, 2008). Participation contributes to accommodate the multiple views on sustainability. These views are reflected in the choice of the assessment criteria as well as in the appreciation of the significance of the values the criteria and their associated indicators take on.
Secondly, participation is also motivated by the precautionary principle, as involving stakeholder groups allows to identify future risks and to challenge apparent certainties in business as usual approaches (Zaccaï, 2002).
Thirdly, participation is key to generate learning effects and to stimulate dynamic decision-making.
No matter how 'participatory' the impact assessment process will be, there will often be competing interests among the group of participating stakeholders. Groups of people with similar views will be formed. These groups can form coalitions, which will merge and shift over time and context. Both the participants and their attitudes change over time (Bell & Morse, 2008). The coalitions' members' views are influenced by discourse, which in turn do also evolve over time and context. For example, a dominant discourse emphasising 'weak sustainability' (which allows for substitution of natural capital by man-made capital) can push participants (or specific groups and/or coalitions) to emphasise economic aspects thereby disregarding ecological aspects. Participation is also key when it comes to learning effects, as these will –often indirectly-increase the policy influence of sustainability assessment exercises, and hence the indicators that give these exercises body.
Fourthly, participation has a direct advantage of bringing in new knowledge and hereby contributing to better assessments. It fosters a better understanding of the decision-making context. And last but not least, linked to the four reasons outlined above, participation contributes to the empowerment of stakeholders and strengthens democratic decision-making.
Participation is closely linked with impact assessment's main information-structuring objective. In order to assess the sustainability of decision options, one will need guidance and clear information, e.g. in the form of indicators. Before being able to use indicators, decision-makers and stakeholders do indeed need to define –or rather to contextually interpret- the sustainability concept more clearly, and this happens through the identification of requirements which cover the array of changes needed to progress towards sustainability. These requirements can then further be translated into indicators in the assessment process. Impact assessment thus becomes a 'mechanism' that brings together decision-makers and experts as well as community

stakeholders together to design and apply indicators that measure progress towards sustainability (see also Fraser *et al.*, 2006).

4.2.4 From principles to process

When analyzing and applying real-life impact assessments, the principles of sustainable development to be fostered, together with the underlying principles of the impact assessment approach and the intended functions of the impact assessment in the decision-making process will define the process and procedures to follow. Acknowledging uncertainties and ignorance, identifying obstacles to integration, involving stakeholders and taking the realities of decision-making into account leads to a stepwise approach to impact assessment. The approach typically consists of a screening step, a scoping step, a set of options to be considered, an analysis and assessment of the impacts of these options, a recommendation for decision-makers and a monitoring and follow-up phase. Yet this description is an oversimplified reflection of reality. There exists many ways to structure information for decision-makers so as to foster sustainability, and the next section provides a few examples from the literature.
The purpose of this endeavour is two-fold:

i. to provide an illustrative overview of the diversity of impact assessment approaches used in energy issues to foster sustainable development;
ii. to analyze one particular case of impact assessment in nuclear energy issues in more detail;

5. Practice of impact assessment in energy issues

5.1 Illustrative overview of impact assessment approaches with regard to energy issues

Various types of impact assessment for sustainable energy development have been used in a variety of institutional contexts. While the aim of this paper is not to provide an exhaustive overview, we will provide examples of different types of impact assessment methodologies as applied in energy issues. The examples are categorized according to the used impact assessment approach – as defined by the initiators – and for each case, a qualitative indication of the acknowledgement of key impact assessment and sustainable development principles is given. We make a distinction between

i. Environmental Impact Assessment (EIA)
ii. Strategic Environmental Assessment (SEA)
iii. Health Impact Assessment (HIA)
iv. Risk Assessment (RA)
v. Sustainability Assessment / Integrated Assessment (SA / IA)

These approaches are understood here in their most general interpretation and do not necessarily reflect the 'official' definition that is valid in certain institutional settings. They are respectively defined as such:
i. Environmental Impact Assessment (EIA) is the systematic process of analysing the environmental (and sometimes broader sustainability) effects of projects.
ii. Strategic Environmental Assessment (SEA) refers to the systematic process of analysing the environmental effects of policies, plans and programmes. Often, the process is equated with a formal procedure based on EIA, as exemplified by the European SEA Directive (Directive 2001/42/EC). Dalal-Clayton & Sadler (2005) state that the boundaries of the SEA field are mapped generically by reference to the function of SEA as a means of integrating environmental considerations into development policy-making and planning.
iii. *Health Impact Assessment* (HIA) is defined as a combination of procedures, methods and tools that systematically judges the potential, and sometimes unintended, effects of a policy,

programme, plan or project on the health of a population and the distribution of those effects within the population. HIA identifies appropriate actions to manage those effects (IAIA, 2006).
iv. In *Risk Assessment* (RA), dealing with uncertainties is central. Risk is defined as a 'situation or event in which something of human value has been put at stake and where the outcome is uncertain'. Assessing risk cannot be done a mere quantitative scientific basis, it needs to take uncertainties and societal sensitivities into account. This evolution led to the rise of 'risk governance' (Health Council of the Netherlands, 2009).
v. *Sustainability Assessment* (SA) is defined as a process that aims to integrate sustainability issues into decision-making by identifying sustainability impacts, but also by fostering sustainability objectives to be achieved. It reflects a desire to achieve defined sustainability objectives, by assessing the extent to which the implementation of a proposal contributes to these objectives when compared with baseline conditions (Pope *et al.*, 2005). The term is often used as synonymously with Integrated Assessment.
Other impact assessment approaches such as Life Cycle Assessment (LCA) for instance, are environmental / sustainability management tools that are often used within one of the major categorizations outlined above.

Approach	Study	Topic
EIA	Bruhn-Tysk & Eklund, 2002	Biofuelled Energy Plants
	Ramana & Rao, 2010	Nuclear facilities
	Bond et al., 2003	Decommissioning of nuclear power plants
SEA	Finnveden et al., 2008	Energy sector s.l.
	Nilsson et al., 2005	Waste incineration tax proposal
HIA	Hamilton, 1984	Energy health risks
	Utzinger et al., 2005	Health impacts of petroleum development and pipeline
RA	Harman et al., 2004	
SA	Afgan et al., 2000	Energy Systems s.l.
	Afgan & Carvalho, 2004	Hydrogen Energy Systems

Table 1: Illustrative overview of the diversity of impact assessment studies in energy issues

The overview provided in Table 1 is just an illustration of the diversity of impact assessment approaches that can be used to support decision-making in energy issues. The scope of application varies from infrastructure development to power plant decommissioning, and from tax systems to the installation of bio-fuelled plants. The methods used in an impact assessment are often a combination of scientific data and participatory developed knowledge, and various impact assessment approaches may provide the most relevant answers depending on the context and the questions asked.
Generally speaking, it appears that a successful impact assessment ideally covers all steps of the decision-making process, and is firmly anchored in the institutional reality of decision-making (often, this means that impact assessments function in a multi-actor and multi-level environment). Every impact assessment should also foster sustainable development. Yet it appears that some of the cited examples do not adequately take sustainable development principles into account. Next to the three principles that are coarsely qualitatively assessed in Table 1, Bruhn-Tysk & Eklund (2002) for example, state that, in the case they analyzed: '…*global effects and effects on the management of natural resources are not assessed, excluding aspects that may affect future generations. Based on this, and since no concerns for sustainable development on a societal level were found, it is concluded that EIA practice (in Sweden) may not, to a full extent, serve as a tool to promote sustainable development*'.

We therefore advocate to base any impact assessment in an energy context on the principles of sustainable development. However, even the multi-dimensional sustainability objectives set out in the European Impact Assessment Framework, that should contribute to '*identify (direct and indirect) economic, social and environmental impacts and how they occur*' (EC, 2009c), are not always reflected in the actual impact assessments. For instance, the impact assessment accompanying the European Strategic Energy Technology Plan (EC, 2009d) mentions environmental externalities, yet fails to provide a satisfactory overview of sustainable development impacts. Fostering sustainable development through impact assessment clearly is a learning process. Section 5.2 sheds light on a particular case in Belgium.

5.2 Case Study: Sustainability Assessment and the Management of Radioactive Waste in Belgium

NIRAS, the Belgian Agency for Radioactive Waste and Enriched Fissile Materials is the Belgian federal Government's agency responsible for the management of radioactive waste. NIRAS is to manage radioactive waste in such a way as to effectively protect the general public and the environment at all times against the potential hazards arising from this type of waste. Radioactivity decays naturally, but until the radioactivity in waste has decreased to a level that is acceptable for public health, measures must be taken to ensure that the radiation cannot cause any harm (NIRAS, 2010).

Amongst its activities, NIRAS is to set up a programme of actions to be undertaken for the long-term management of all radioactive waste, embodied in a Waste Management Plan that NIRAS aims to submit to the Belgian federal government in 2010. As the Waste Management Plan will give rise to a strategic decision, it needs to be submitted to an environmental assessment at strategic level: a strategic environmental assessment (according to the Law of 13 February 2006 concerning the environmental impacts of certain plans and programmes and the participation of the public in the elaboration of plans and programmes concerning the environment).
The SEA emphasizes the qualitative description and comparison of different management alternatives that are not yet location-specific (thereby differing from a regular EIA).

An essential part of the decision-making process – both for intrinsic and legal reasons – is the consultation of the public on the management of highly and long-living radioactive waste. NIRAS chose to organize a societal consultation prior to the legal procedure. This consultation consisted of two main elements:

- the NIRAS dialogues and the inter-disciplinary conference, where NIRAS collected the participants' opinions and concerns with regard to long-term radioactive waste management
- the Public Forum, which yielded information on the values, norms, arguments and considerations that should underpin decisions regarding the long-term management of radioactive waste.

NIRAS commissioned the King Baudouin Foundation to organize a Public Forum in full independence. This decision was taken after the poor results of previous NIRAS-organized public dialogues and after critics issued by external experts airing their concerns about possible conflicts of interest and lack of transparency (Laes *et al.,* 2009). During that Public Forum, 32 Belgian citizens debated (together with experts) around the broad topic of 'long-term management of long-living and highly radioactive waste'. The citizens' input was collected in a Report (King Baudouin Foundation, 2010).

The Public Forum is as an empirically tested example of participatory impact assessment (inspired by the idea of a 'consensus conference' as developed by the Danish Board of Technology) to support decision-making. This Public Forum experience is to be seen as a step in a learning process towards the design and application of participatory impact assessment for sustainable development. Although interesting, the process entails some risks, such as the risk for trivialization of complex scientific facts and the risk of a manipulation of the debate by powerful actors and stakeholders. Nevertheless, we believe this to be a fruitful case for analysis.

A review of the Public Forum's final report keeping the five key impact assessment and sustainable development principles in mind reveals some of the underlying thoughts and motivations of the participating stakeholders. Furthermore, a parallel narrative analysis of the NIRAS draft waste management plan dated June 7, 2010 (NIRAS, 2010), sheds light on the actual uptake of the Public Forum's recommendations through a sustainable development lens.
The *global responsibility* principle is implicitly mentioned in the Public Forum's report: '*we advocate to explore the possibilities for cooperation with other countries*'. The NIRAS waste management plan discusses the question, especially with regard to an internationally shared geological disposal of the waste, yet underlines the expected difficulties regarding responsibilities.
Integration is recognized when the multifaceted character of the radioactive waste issue is considered in the Public Forum's report: '*..it has many aspects, a broad impact and lots of stakeholders –if not the whole of society- both now and in the distant future'*. This realization is linked to participation, as the report goes on stating: '*that's why we find it important to think about this issue. It concerns everyone. There is no one single group that can offer a solution'*. Integration is also emphasized in the NIRAS waste management plan, both from the multidimensional perspective of the impacts to be considered (referring to the SEA which includes the environmental, health, technical, scientific, economic and societal dimensions), as well as regarding the integration of stakeholders in the decision-making process (the Public Forum itself). However, it is important to mention that the Public Forum was not a legally compulsory initiative, it remained an informal process – that admittedly –partly- influenced the NIRAS waste management plan. The challenge lies in a formalisation of future stakeholder engagement.
The Public Forum mentions the *equity* principle as follows: '*we think it is important to apply the equity principle here. This amounts to the fact that no one can take unidirectional advantage from a good whose disadvantages are carried by others'*…or '*we want to show the future generations how we thought about this issue and explain why we made this choice. This is important so that they can work on solutions in full knowledge of what happened before'*. The waste management plan mentions intra- and inter-generational equity from a basically instrumental point of view. Indeed, NIRAS states (NIRAS, 2010 p126) that the geological disposal solution should be implemented rapidly, so as not to keep the municipalities in uncertainty and to keep the management costs down (intra-generational equity), and so as to avoid putting the responsibility on the future generations (inter-generational equity). The intergenerational equity argument is also mentioned on NIRAS, 2010 p70, where there is an explicit reference to the Public Forum's report.
Precaution is implicitly guiding the stakeholders' decisions in the Public Forum's report, yet it is not mentioned explicitly. One of the leading questions is *'how can we guarantee that our environment and health will not be damaged*?'. The precautionary approach is actually used as a strategy to deal with uncertainties, especially in the long run, as indicated by the fact that the decision that will be taken is a 'decision in principle', forming the first step of a long decision-making process. The report also states '*we want maximum certainty and the necessary resources to achieve that certainty need to be ensured*'. And further: '*there need to be enough resources for at least two scenarios: the reference scenario and the backup scenario*'. This 'keeping options open'-stance is a typical feature of the precautionary principle. This approach ultimately led the stakeholders to issue a recommendation inspired by the principle of inter-generational equity (see above), stating that the proposal of NIRAS (deep underground waste storage) should be reversible for a period of at least 100 years.
Participation was self-evidently a key element of the Public Forum, which was explicitly set up as a format to include non-experts in the decision-making process. The report states: *'we provide information about the values, norms, arguments and considerations that need to be considered when taking a*

decision on the long-term management of radioactive waste (…)', hereby acknowledging the fact that such a decision cannot be based on known scientific facts alone. The NIRAS waste management plan devotes a whole section to participation, but leaves ample space for interpretation, as the organization of the participation is said to be dependent of the principle decision as well as of the decision-making phase (NIRAS, 2010 p139). On p. 182, NIRAS states that it aims at continuing the societal consultations (..), even those that are not legally compulsory.
The Public Forum allowed to pin-point the reality of the variety choices that can be made in the radioactive waste management debate, refuting the image of decisions generated by mere scientific knowledge. Rooted in the principles of sustainable development, the Public Forum's very initiation, as well as the recommendations it yielded, does amount to a broad interpretation of 'participatory sustainability assessment'. Its recommendations have been partly taken up by the draft waste management plan, although assigning particular sections of the plan to particular remarks made in the Public Forum's report is often challenging.

Pope (2006) defines sustainability assessment as '*embracing a range of processes that all have as their broad aim the integration of sustainability concepts into decision-making, processes that may carry the labels sustainability appraisal, sustainability impact assessment, or integrated assessment, amongst others*'. Devuyst *et al.* (2001) provide a more narrow definition, by defining it as '*a formal process of identifying, predicting, and evaluating the potential impacts of a wide range of relevant initiatives and their alternatives on the sustainable development of society*'. Scholars have developed a range of methodologies (Lee, 2006) and typologies (Pope *et al.*, 2005) to structure the comparatively recent sustainability assessment field.
Given the value-laden and at least partly subjective definition of sustainability and its associated objectives, sustainability assessment must be supported by participatory exercises, which will in turn lead to more transparent decision-making. The theory and practice of participatory sustainability assessment was elaborated by Kasemir *et al.* (2003), within the frame of the European ULYSSES project (*Urban Lifestyles, Sustainability and Integrated Environmental Assessment)* project. The idea proposed by the Public Forum on radioactive waste management is similar: through a combination of scientific knowledge (expert input consisting of mathematical models and/or scenarios, background information *etc.*) and citizen knowledge (the opinions and concerns of 'lay' citizens), a structured sustainability discussion arises. The systematic application of decision-support tools within such as discussion, and the focus on the impacts of different decision options, ensures that the exercise contributes to sustainable decision-making. So is all for the best in the best of all worlds? Well, not exactly, as even a soundly designed, participatory assessment exercise is always performed within a particular context. In the context of the case study, the management of radioactive waste is framed within the sustainable development debate, but this again is a normative choice. Furthermore, the time dimension is a key element of the radioactive waste debate, as reflected *e.g.* in the retrievability debate (referring to the capability of retrieving waste emplaced in geological repositories).
Let's have a closer look at the interpretational limits of sustainability and at these limits' relevance for nuclear energy issues.

6. Nuclear energy and the interpretational limits of sustainability

Despite its normative nature and the plethora of definitions, sustainable development does not leave the door open to all interpretations. Sustainability has clear and unambiguous interpretational limits and these should be respected. Lele (1991) makes a distinction between "trivial" or "contradictory" (mis)interpretations and meaningful ones. Meaningful interpretations are those who consider sustainable development as a process of change, harmoniously integrating traditional development objectives, such as socio-economic and institutional objectives, with

environmental objectives; while trivial interpretations only use 'sustainable' in the sense of 'ongoing, lasting'.
Besides this fairly obvious caveat, a meaningful definition of sustainable development has limits, which are not all to be left 'open for interpretation'. Rockström *et al.* (2009) for instance define a 'safe operating space for humanity', establishing underpinned 'limits to growth' or 'planetary boundaries'.
Furthermore, sustainability is a process of directed – sustainability oriented – change; and not a fixed state of harmony, nor a defined end-state (Robinson, 2004); as society, the environment and their interaction are subject to a continuous flow of change. The societal transition towards sustainable development is a destiny-oriented long voyage and not a final destination. Therefore it is sometimes argued that sustainability – per definition – can never be achieved, and that its perfect realization eludes us. This type of reasoning might be a pitfall and an argument to escape from the societal commitment to the objective. Instead sustainability can and should be achieved – it ultimately depends on societal and political will – and should be regarded as a continuous search for a delicate equilibrium in a dynamic setting. Thus the constructive ambiguity of the concept referred to in section 2, is a strength. We based our definition of sustainable development on a five key principles, and subsequently analyzed the function and process of impact assessment for sustainable development, through a case study on radioactive waste management.

Yet the key question in this case remains: is nuclear energy sustainable at all? If it is not the case, any sustainability assessment on aspects of the nuclear energy chain (power plant location, decommissioning, radioactive waste management *etc.*) will actually be un-sustainable, however well designed, due to the very nature of the operations it assesses. Off course, the *existing* waste problem needs to be solved anyway. The question whether sustainability assessments then act as a smokescreen to grant nuclear energy a 'green' or 'sustainable' image is complex, and scholars disagree on the answer to provide. This often depends on the normative views of the authors, and their interpretations. Various scholars stress different sustainability principles, and these differences in emphasis will greatly influence positions on the nuclear energy issue. Although our narrative analysis outlined in the previous sections is based on the five principles of the Belgian Federal Planning Bureau (which are widely recognized as key sustainability principles by scholars worldwide however), this remains an –informed- partly normative selection of principles.

Robinson's (2004) definition of sustainable development stresses that developmental and environmental objectives should be reconciled, as well as the views and interests of different stakeholders, and various temporal and spatial scales. We recognize the integration principle outlined above. But what exactly does this reconciliation amounts to? Haughton (1999) states that equity should act as the central principle in sustainable development. He distinguishes five equity principles: Inter- and intra-generational equity, geographical equity, procedural equity, inter-species equity.
Here again, what one calls intergenerational equity will be determined by the normative views and values held by the person. The Public Forum of the nuclear waste management case study recommends the 100 years reversibility check and as such takes a pragmatic stance towards the principles of intergenerational equity. Meadows (1998) defines sustainability as 'good lives for all people in harmony with nature'. Is nuclear energy in harmony with nature?
Every sustainability assessment needs to have a defined scope to avoid endless discussions and to ensure manageable recommendations. But this does not preclude participants in a sustainability assessment exercise centred on nuclear energy to reflect on the sustainability of nuclear energy as such. Recently, the debate on the sustainability of nuclear energy has been centred on the avoided greenhouse gas (GHG) emissions. Duffey (2005) for instance, points to relevant questions when stating that conservation, renewables and efficiency alone will not significantly reduce the GHG

burden. However, it is overly un-critical to state '..*nuclear energy supports and enables the World in its journey to a sustainable, safe and secure energy future'* (Duffey, 2005). The International Atomic Energy Agency's Nuclear Energy System Assessment (NESA) assists Member States in assessing their long range strategic planning for existing or future nuclear energy systems. The Nuclear Energy System Assessment is a holistic approach that uses an internationally validated tool — the INPRO methodology — to support long-term planning and strategic decision-making on nuclear energy development and deployment. The sustainability of nuclear energy production as such is not questioned (Sokolov & Beatty, 2010).

Adamantiades & Kessides (2009) hold a more balanced view. Although they recognize the contribution of nuclear energy to the reduction of greenhouse gas emissions, they list a series of 'significant issues' that explain the reservations of the public and decision-makers alike: nuclear safety, the disposal of radioactive wastes and proliferation of sensitive nuclear materials and technologies. Verbruggen (2008) decomposes sustainability in ten dimensions, on which nuclear energy scores badly: *e.g.* on democratic participation, nuclear energy is mainly characterized by technocratic decision-making; on global accessibility it scores badly as it is capital-intensive and as it entails proliferation risks. On ecological aspects: it is a low-carbon technology, yet the waste problem is still unsolved. The risks posed by nuclear energy are not insurable and safety remains an issue. Furthermore, the technological evolution of nuclear energy is uncertain, *etc.* Based on these findings, Verbruggen (2008) rejects nuclear energy as a sustainable energy source.

This brief elaboration on sustainability and nuclear energy first of all proves the wide array of views on the issue; the opinions of most scholars and citizens are to be situated somewhere on that continuum of views, yet the basic principles of sustainable development – as outlined in section 2- and the interpretational limits of the concept should guide any decision on our energy future. Impact assessments of all kind, and especially sustainability assessment, can only contribute to a more sustainable energy future if the very context in which they are applied, fosters sustainability.

The major issue of the sustainability of nuclear energy itself should always be kept in mind when applying sustainability assessments on sub-aspects of the nuclear energy chain of processes. This should off course not lead to a kind of intellectual paralysis; instead these thoughts can trigger discussions on sustainability, which will hopefully in turn lead to a better informed and more sustainable energy future.

6. Conclusion

Sustainable development can be operationalized in a set of generic principles and context-dependent objectives, and can be interpreted in many different ways. However, the interpretational limits of the concept need to be kept in mind. Impact assessment methodologies have been used to structure and inform decision-making processes so as to steer these towards sustainable development. The actual influencing power of these assessments can be assessed from different perspectives. This paper reflected on the underlying principles and discourses underpinning the use of impact assessment for sustainable development, focussing on energy issues. Through a case study on radioactive waste management, we aimed at broadening the debate to include the wider context in which impact assessments are performed. The controversy on the sustainability of nuclear energy has not been settled, and should imperatively be kept in mind when performing sustainability-oriented impact assessments on nuclear energy issues.

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