Advantages & disadvantages of thorium fuelled nuclear power when generated in the **Liquid Fluoride Thorium Reactor** compared to uranium fuelled nuclear power & stakeholders in the decision making process.
The Liquid Fluoride Thorium Reactor (LFTR) is an innovative nuclear reactor design that has important potential benefits over traditional reactor designs. The Hanzehogeschool is advised to conduct further research into this technology.

It is said to produce much less nuclear waste, 99.99% of which is stable after 300 years. The reactor is inherently safe. Meltdown & gas explosion, the main dangers in traditional reactor designs, have been designed out of the LFTR. There is enough thorium to power the world for tens of thousands of years. LFTR electricity might be cheaper than traditional nuclear power and even coal. Thorium can be used for nuclear weapons but is less suited than uranium, and can even be used to break down plutonium from old nuclear weaponry. The thorium decay chain produces unique isotopes that are expected to be very effective at fighting cancer.

Uranium is currently used instead of thorium because in the early days of nuclear power uranium had more desirable characteristics, like its suitability for weapons production. Since then, a development gap developed that thorium has to catch up with. The LFTR is still in the development phase and faces a number of challenges, although these are expected to have solutions.

Governments and businesses won’t invest because of its long development time and unknowns. A list of stakeholders in the development of thorium-fuelled nuclear power has been created to identify who or what the forces are that exert influence over- or are influenced by the development of this technology.
I’d like to thank my thesis supervisors Dr. Egbert Dommerholt and Mrs. Conny Dröge-Pott Msc., without whom this project could not have been realised. Their guidance has been invaluable to the design and execution of this research. I am grateful for allowing me the freedom I desired while providing the boundaries I needed.

I am also very grateful to Dr. Jan Leen Kloosterman of the Reactor institute Delft for providing me with a wealth of information on the Liquid Fluoride Thorium Reactor.

Special thanks to Marieke van der Werf whose insight into Dutch decision making was particularly helpful.

Finally, thanks to all those that consented to be interviewed for this report, your contribution is much appreciated.
# Table of Contents

1 Introduction 11

2 Methodology 13
2.1 Introduction to methodology 13
    2.1.1 Research onion 13
    2.1.2 Interviews 13
    2.1.3 Theory 14
    2.1.4 Stakeholders 14
    2.1.5 Recommendations 15
2.2 Data collection 15
    2.2.1 Research question 1 15
        2.2.1.1 Literature 16
        2.2.1.2 Expert interviews 17
    2.2.2 Research question 2 18
    2.2.3 Research question 3 19

3 Basics 21
3.1 What is thorium? 21
3.2 What is radioactivity? 21
3.3 Nuclear fission & power generation 21
3.4 Isotopes 21
3.5 Elements turning into others: transmutation 21
3.6 Molten Salt Reactors 21

4 The Liquid Fluoride Thorium Reactor (LFTR) vs. the Light Water Reactor (LWR) 23
4.1 The Light Water Reactor (LWR) 23
4.2 The Liquid Fluoride Thorium Reactor (LFTR) 25

5 Supposed benefits 27
5.1 Cleaner 29
    5.1.1 The Light Water Reactor (LWR) 29
    5.1.2 The LFTR 29
    5.1.3 Conversion rate 31
5.2 Safer 33
    5.2.1 LWR 33
        5.2.1.1 Steam explosion 33
        5.2.1.2 Meltdown 33
    5.2.2 The LFTR 35
        5.2.2.1 Steam explosion 35
        5.2.2.2 Meltdown 35
        5.2.2.3 Negative temperature coefficient of reactivity 35
Executive summary

The Liquid Fluoride Thorium Reactor (LFTR) is a promising, innovative reactor design that uses liquid-instead of solid fuel, and thorium instead of uranium, giving it considerable benefits over “traditional” uranium-fuelled Light Water Reactors (LWR’s). The Hanzehogeschool is advised to continue research into this technology.

It is claimed to produce 35 times less nuclear waste than the LWR, 83% of which is stable after 10 years, 17% after 300 years, and 0.01% is plutonium waste that requires long time storage. There is even a design that runs on existing nuclear waste, providing a solution to the current waste problem.

Meltdown & gas explosion, the main dangers in LWR’s, have been designed out of the LFTR, and the “negative temperature coefficient of reactivity” and a frozen salt plug at the lowest point of the reactor further protect it against temperature increases.

There is enough thorium on earth to power the entire world for tens of thousands of years, compared to 100-230 years for uranium at the current rate of consumption.

LFTR electricity might well be cheaper than the LWR’s, and possibly even coal. This depends on what the final design will look like, so it is too early to say for sure.

Thorium can be used for nuclear weapons but is less suited than uranium. Parties controlling a reactor could use it for weapons production, but theft of material by third parties is unlikely. It can even be used to break down plutonium from old nuclear weaponry.

The thorium decay chain produces unique isotopes that are expected to be much more effective at fighting cancer than the isotopes that are currently being used.

The reason uranium is currently used instead of thorium is because in the early days of nuclear power uranium was better suited for several reasons, an important one being that it was better for weapons production. Since then, a huge development gap developed that thorium has to catch up with.

A test reactor (Molten Salt Reactor Experiment/MSRE) has been in operation in the 1960’s, which demonstrated many of the theoretical processes.

The LFTR is still in the development phase and faces a number of challenges, although these are expected to have solutions. These are the chemical processing installation for cleansing of the liquid fluoride, the material to contain the liquid fluoride, handling beryllium, development time (15-20 years), and cost-efficiency. The latter two are why governments and businesses are not eager to invest.

A list of stakeholders in the development of thorium-fuelled nuclear power has been created to identify who or what the forces are that exert influence over- or are influenced by the development of this technology. Support for developing the technology probably has to come from (national) government(s). In the Netherlands energy policy is made at the “Table for industry, large-scale energy production and Emission Trading Systems”, and the organisations represented there are the stakeholders in Dutch energy policy.

If it lives up to its expectations, existing energy producing companies could suffer heavy competition from the LFTR. Several start-ups, as well as the countries India, China, U.S., Norway, Japan, France, and Russia are currently developing thorium-based nuclear power. China is leading the effort, the country expects to have commercial Molten Salt Reactors in 20 years time.
It sounded like wishful thinking, but if there were truth to this it could have a massive impact on global energy production, renewable energy production, and on anyone operating in the sector.

Renewable energy’s unique benefits are that it does not harm the environment and there is plenty of it, making it the most sustainable option for our common future, but what if these benefits would cease to be unique? What if another energy source becomes available that has the efficiency and reliability of nuclear energy production but almost none of its disadvantages? This could have dramatic consequences for the entire renewable energy sector, an industry that saw $257 billion of new investments in 2011 and employs over 5 million people. (REN21, 2012)

It is therefore of considerable strategic importance to the International Business School “Lectoraat” to assess whether the benefits associated with the Liquid Fluoride Thorium Reactor, or LFTR (pronounced: Lifter) are a realistic prospect or an exaggeration. This was achieved by consulting secondary sources, which were then validated and complemented through interviews with experts in the field of nuclear power.

If the LFTR’s supposed benefits are found to be accurate, the next question that needs to be answered is who or what the forces are that exert influence over- or are influenced by the development of this technology. This was done by creating a list of stakeholders in the development of this technology, and identifying what their respective roles and views are.

The outcomes of this research were then used for making recommendations to the Hanzehogeschool’s International Business School “Lectoraat” as to whether this is a subject that warrants follow-up research in future theses. If further research is conducted, this thesis is to serve as a foundation for future researchers to build on. It provides a solid base of information and indications to which areas deserve to be explored further and in depth.

The report starts with the method (chapter 2) that was used to find answers to the questions this research aims to answer. Because this report aims to be comprehensible to all, including those who have a limited understanding of (nuclear) physics, chapter 3 provides basic information about some of the fundamental concepts associated with thorium and nuclear power generation. Chapter 4 explains how the LFTR works and how it differs from the most common type of nuclear reactor in operation worldwide, the Light Water Reactor (LWR). Chapter 5 discusses the LFTR’s supposed benefits compared to the LWR. The historical reasons that led to thorium being side-lined in favour of uranium by the global community are discussed in chapter 6. Chapter 7 lists the challenges that the LFTR’s development still faces. Chapter 8 outlines who or what the stakeholders in the LFTR’s development are and briefly discussed their role, a more detailed description of which can be found in appendix E. Chapter 9 then combines the supposed benefits of chapter 5 with the challenges of chapter 7 to arrive at the report’s findings and conclusions, and make recommendations on how to proceed from here.
This graduation project report is different from traditional International Business School graduation projects. Instead of researching a particular issue or case for a company, this research investigates an innovative technology that could have a great impact on many companies, those in the renewable energy industry in particular. The “research onion” in “Research methods for business students” (Saunders, et al., 2009, p. 108) is especially suited to “traditional” IBS theses but when we apply the principles of the “research onion” to this project the following applies:

The research philosophy best suited to this project was pragmatism. Whichever methods led to successfully answering the research questions were the methods to employ. These were a theoretic foundation from secondary sources, further complemented and validated by expert interviews, as well as stakeholder interviews. The research approach is a combination of deductive and inductive. It is deductive because it starts with theory that is then put to the test in expert interviews, but some of the findings were rather novel, especially some of those relating to stakeholders in the Netherlands and decision making which could be considered inductive. Of the strategies suggested, this research is most like the “case study”; the “case” here being the “phenomenon” of the LFTR. It is descriptive and explorative; it aims to create a foundation of knowledge on a relatively new subject. It can be considered a multiple method qualitative research approach, as it combines secondary data analysis with interviews. The time horizon for this project is cross-sectional, as the current position of thorium as a nuclear fuel is being examined (Saunders, et al., 2009, pp. 108-156).

For all the interviews conducted, semi-structured interviews were deemed best suited to obtaining the information needed because some structure is desirable to limit the scope of the matters discussed, but new information was also expected and welcomed as this research is explorative in nature (Saunders, et al., 2009, p. 323). The goals of the expert interviews were to verify the theory found in secondary sources, as well as finding new information and identification of new stakeholder groups. The goals of the stakeholder interviews were to learn about their knowledge of-, and stance on the LFTR, as well as identifying new stakeholder groups. Before every interview the intentions and goals of the research and interview were explained, to ensure the right information would be conveyed, and enhance the validity of the findings (Saunders, et al., 2009, pp. 328,329). The interview with Dr. Kloosterman was conducted at the reactor institute in Delft. Telephone interviews were considered the best option in all other cases because of easier access and an increased likelihood of participants agreeing to an interview, and because they sufficed for getting the information needed.

A time around the middle of the week was chosen when possible to increase the likeliness of interviewees being receptive to conducting an interview, and reduce participant error. Participants were always offered the possibility of anonymity to increase the chances that they would consent to using their statements and to reduce participant bias. Both measures were taken to reduce threats to reliability (Saunders, et al., 2009, p. 156).
The interviews were always recorded and digital copies of the file were made immediately following the interview to prevent any loss of information (Saunders, et al., 2009, pp. 339,341). The recording was then translated into text: verbatim + summarized texts in case of the expert interviews and “politicians” stakeholder group, and text summaries in all other cases. These texts were then sent to the interviewees for verification if they indicated in the interview that they so desired, as a form of triangulation. (Saunders, et al., 2009, p. 298) All interviews went satisfactory and yielded valuable results. Summaries of all interviews can be found in appendix A.

2.1.3. Theory

What sparked the beginning of this research was the notion that the Liquid Fluoride Thorium Reactor (LFTR) has the potential to solve today’s energy crisis. If true this would have (competitive) implications to almost every sector of industry imaginable and to the renewable energy sector in particular. The general question that needed to be answered therefore was whether there was truth to these claims, and if so, to what extent.

After careful deliberation and close contact with the project supervisors the main research question was defined as:

1. What are the advantages and disadvantages of thorium fuelled nuclear power when generated in the LFTR compared to uranium fuelled nuclear power?

In order to answer this question a thorough understanding of thorium fuelled nuclear power in the LFTR was required. This could be achieved largely from secondary theoretical sources of information in the form of reports, articles, and other written material, and for reasons of triangulation, validation of the theory by reliable expert opinions was also sought. Experts on thorium fuelled nuclear power and the LFTR are not abundant however so it was crucial that the authorities that exist would consent to participate in this research. Experts also had to be approached carefully; those who are positive about the future of thorium fuelled nuclear power might be biased about the subject (e.g. confirmation bias (Science Daily, 2013)). They might be so enthusiastic about the prospect of thorium solving the energy problem that they overstate its positive effects and their likeliness, while understating or even ignoring downsides. Therefore in addition to getting their side of the issue, counterclaims made against the LFTR technology were presented to them to comment on, adding to the validity of the findings.

2.1.4. Stakeholders

Claims are made about thorium fuelled nuclear power in the LFTR’s considerable benefits and if there is truth to these, the question that arises is why more is not being done to develop this technology. Part of this question can be answered by consulting secondary written sources, but to come to a deeper understanding of the current situation, the stakeholders in the development of this technology have to be identified. If a comprehensive picture is painted as to who or what the forces are that exert influence over- or are influenced by the development of this technology, it will be better understood what is keeping it from being developed and what could be done to influence this.

International stakeholders are discussed, but emphasis is placed on stakeholders in the Netherlands. In the question of thorium fuelled nuclear power transnational thinking is essential because of the amount of resources and political will required, but as this research was conducted in the Netherlands it was decided to identify stakeholders in this country as a way of limiting scope, while serving as a general model for doing the same in other nations.
The second research question that would need to be answered therefore was defined as:

2. Who are the stakeholders in the development of thorium fuelled nuclear power?

This was achieved by creating a preliminary stakeholder list using a combination of written sources and brainstorming. The “snowball sampling” technique was then used to add to the preliminary list, which comes down to asking representatives of these stakeholders and other experts who they consider (important) stakeholders (Reed, et al., 2009, p. 1937).

2.1.5. Recommendations

Finally, this research project is conducted for the International Business School-“Lectoraat” and has as its goal to explore whether there are sufficient grounds to warrant further “lectoraat” research into (thorium fuelled) nuclear power. Recommendations will be made about the former and if further research is found warranted, this report will serve to identify areas which can be explored in more detail in future “lectoraat” theses. This was defined in research question 3 as:

3. What is the significance of thorium fuelled nuclear power when generated in the Liquid Fluoride Thorium Reactor to (renewable) energy business models, and with that, to the IBS-lectoraat? Are there sufficient grounds to warrant further research into the subject?

This assessment will be made based on the researcher’s findings. Should convincing evidence indicate that the claims about thorium fuelled nuclear power in the LFTR are a grave overestimation further research by the IBS-lectorate will not be recommended. Should this technology look promising however, research done at IBS might well add to the development of an important new technology, or at least being aware of its existence and able to anticipate on these developments could be of considerable strategic value.

2.2. Data collection

2.2.1. Research question 1

In order to answer research question 1 “What are the advantages and disadvantages of thorium fuelled nuclear power when generated in the LFTR compared to uranium fuelled nuclear power?” the following sub-questions had to be answered:

1.1 What is thorium fuelled nuclear power?

1.2 What are the advantages and disadvantages of LFTR reactor design compared to traditional nuclear reactor design?

1.1

To increase overall reliability, transparency is required. To achieve this, the literature selection method will be outlined and special attention will be given to matters of validity.

First, basic information about the element thorium and using it as a nuclear fuel for generating power had to be collected to lay a theoretical foundation for the researcher, as well as for anyone reading the thesis. The aim is to make the subject accessible to anyone, including those who do not have extensive knowledge of (nuclear) chemistry and physics. This information was collected by consulting several different web pages by reputable authors, i.e., with chemistry-related PhD’s and university websites, which all provided the same information and were thus deemed reliable.
1.2

Sub research question 1.2 was answered by explaining how using thorium as a fuel in the LFTR supposedly differs from the traditional method of using uranium as a fuel in nuclear reactors, and what its advantages and disadvantages are. This question includes waste, safety, costs, power output, and by-product properties.

2.2.1.1. Literature

In order to reach a high level of source validity the following procedure was followed: the theory about the advantages of using thorium as a fuel in the LFTR came from 3 main articles, which were compared to-, and complemented by each other. These were further complemented by 2 reports on the LFTR created for the governments of the Netherlands and the United Kingdom. These 5 articles and reports were selected after reviewing many other articles and reports that showed potential at first, but were later rejected in favour of these, as suggested by Saunders (Saunders, et al., 2009, p. 272).

All articles have been written by reputable authors and were published by respected and reliable organizations. For a full description of their credentials see appendix C.

An important source of information about the supposed benefits of using thorium as a fuel in the LFTR, is the article “Liquid Fluoride Thorium Reactors” (Hargraves & Moir, 2010) published in the journal American Scientist (American Scientist, 2013). It is is published by Sigma Xi “The international honor society of science and engineering” (Sigma Xi, 2013) and gives a comprehensive overview of the LFTR’s supposed benefits. It has been written by Dr. Robert Hargraves Ph.D and Dr. Ralph Moir Ph.D., both of whom boast impressive CV’s in fields related to (nuclear) physics and energy.

Both are members of the board of advisors of Flibe Energy, a thorium start-up, (Flibe Energy, 2013) which could indicate two things: 1. They are biased because putting thorium in a favourable light is good for Flibe Energy, creating a threat to validity. 2. They are on its board because they are experts in their field and have a genuine desire to develop a technology they believe in. It is hard to conclusively assess which is true, but being aware of possible bias is prudent. Other sources were consulted to cross-examine their claims.

The information from this article was compared to- and complemented by information from the article “Molten salt reactors: A new beginning for an old idea” (LeBlanc, 2009) published in the Elsevier journal “Nuclear engineering and design” (Elsevier, 2013). “David (LeBlanc-LP) is a nuclear scientist at the Department of Physics, Carleton University, Ontario” (Itheo, 2010).

As a third comprehensive source of information, the theory was compared to- and complemented by information from the report “High Efficiency Nuclear Power Plants Using Liquid Fluoride Thorium Reactor Technology” (Juhasz, et al., 2009), published by NASA.

The theory was further complemented by information from “Toepassing van Thorium in de Nucleaire Spiljstofcyclus” (Application of thorium is the nuclear fission cycle) (Hart, 2011) a paper created by NRG for the Dutch ministry of Economic Affairs, agriculture and innovation, and information from “Comparison of thorium and uranium fuel cycles”, a report created by the National Nuclear Laboratory for the United Kingdom’s Department of Energy and Climate Change.

What should be noted is that neither report recommends their governments to start developing thorium/LFTR technology, due to the technological immaturity and a possible overstatement of its advantages. The NNL report only sees a role for thorium as a plutonium (nuclear waste) disposition-, or very long term energy strategy. It does recognize the possibility of thorium becoming more interesting to the UK in
the future, and recommends a low level of engagement to keep up with developments. (National Nuclear Laboratory, 2012, p. 4) (Hart, 2011, pp. 1,2) It is important to remember however that these reports assess thorium/LFTR on its benefits to these particular countries, rather than to the world as a whole. Including sources with different stance on the matter based on the same information will further benefit the validity of this report’s findings.

2.2.1.2. Expert interviews

After clearly defining the LFTR’s supposed benefits the researcher had reached a level of knowledge (Saunders, et al., 2009, p. 328) needed for conducting the expert interview, and arguments refuting these claims were researched. These came from the articles and reports mentioned above as well as other articles, report, and online sources. Arguments with less solid sourcing were sometimes included based on their repeated appearance, to be verified during the expert interview.

The counter-arguments were to be used in the interview with Dr. Kloosterman, one of the Netherlands’ leading nuclear physicists and an authority on the LFTR, to see whether he could present satisfactory retorts to these. Dr. Kloosterman is:

“Associate Professor of Nuclear Reactor Physics
Section Head Nuclear Energy & Radiation Applications (NERA)
Program Director Sustainable Energy Technology (SET)” (Kloosterman, 2012)

Next, an interview with Dr. Kloosterman was set up. Experts on the LFTR are rare worldwide, and even more so in the Netherlands, so it was important that an interview was successfully secured. To increase the chance of success, a letter detailing the nature of this research and a request for an interview was sent from the Hanze hogeschool to the reactor institute Delft. Approximately one week later the the office of Dr. Kloosterman was contacted to follow up on the letter and set up an appointment for April 23rd².

The interview was then prepared with the help of Anna Berbers, PhD student at the department of commucation at the KU-Leuven in Belgium and former lecturer qualitative research, interviewing, and focus groups at the University of Amsterdam. A draft containing the counter arguments as well as additional questions was created by the researcher, which was then discussed and edited with Ms. Berbers and a third person until it was deemed up to standard by Ms. Berbers. The interview was practiced several times and further edited before being conducted with Dr. Kloosterman at the reactor institute on April 24th.

Dr. Kloosterman indicated that the interview summary sent to him afterwards was excellent and added information about radio-toxicity. Every piece of information of the summary was then compared with the theory in the report, and statements supporting the theory and relevant new information were added. Much information from this interview was used in the “Challenges” chapter of this report, which discusses the challenges that have to be overcome for the LFTR to be developed.

One of the things that became clear is that an important aspect that still requires much research is the chemical processing installation for continuous cleansing of the salt mixture. The chemical aspects are not Dr. Kloosterman’s area of expertise however so he recommended an expert who specializes in these matters.

Due to regulatory reasons at the institution he works for his name cannot be mentioned in this paper but the source is an expert in the field of nuclear chemical engineering at a renowned research institution. This source will from hereon be referred to as “Nuclear chemistry expert”. Should any doubt exist about the authenticity and reliability of this source, his credentials are known to the Hanzehogeschool Groningen.

² Date later postponed to April 24
An interview was set up through e-mail, after which a series of questions specifically about the chemical aspects of the LFTR was created. These interview questions were again discussed and tested with Ms. Berbers and the interview was conducted on March 2\textsuperscript{nd}. A summary of this interview was created and this information was compared to the theory in the report and what had been said by Dr. Kloosterman. It confirmed some of the things said by Dr. Kloosterman and provided new interesting insights into the chemical aspect of the LFTR. These findings were added to the report.

Apart from these 2 (thorium) nuclear power experts no others were interviewed, as a way of limiting scope. This was decided in collaboration with the thesis supervisor.

1.3 Why is thorium not being used as a fuel today?

Regardless of thorium and the LFTR’s supposed great and many benefits it is not currently used as a nuclear fuel. To understand why, the reason must be uncovered and this knowledge used to instigate change if the theory does indeed justify thorium being pursued as a future nuclear fuel.

This was done by consulting the secondary theoretical sources used for answering questions 1.1 and 1.2 and further confirmation of this information was given during the expert interviews.

2.2.2. Research question 2

In order to answer research question 2 “Who are the stakeholders in the development of thorium fuelled nuclear power?” the following sub-questions had to be answered:

2.1 Who are the stakeholders in the development of thorium fuelled nuclear power in the Netherlands?

2.2 What are these parties’ considerations regarding developing- or not developing thorium fuelled nuclear power?

2.3 Who are the international stakeholders in the development of thorium fuelled nuclear power?

2.4 Which parties are currently involved in actively developing thorium based nuclear power?

2.1., 2.3 & 2.4.

Sub-research question 2.1, 2.3., and 2.4., were answered by creating a preliminary list of stakeholders by brainstorming individually and with others. This list was then complemented by literature source, and interviewing experts on (thorium fuelled) nuclear power, as well as representatives of these stakeholder groups and asking them who they felt were important stakeholders, using the “snowball sampling” technique (Reed, et al., 2009, p. 1937). By doing so it was learned that policy makers/influencers are vital stakeholder groups because developing the LFTR requires a coordinated effort and large amounts of resources.

A boundary was established as to which stakeholder (groups) to include, and which to exclude from the stakeholder list. A definition of stakeholder is given in the article “Who’s in and why? A typology of stakeholder analysis methods for natural resource management”:

“(…) individuals, groups and organisations who are affected by or can affect those parts of the phenomenon (this may include nonhuman and non-living entities and future generations);” (Reed, et al., 2009, p. 1933)

In the interview of Dutch politician M. van der Werf it became clear that in the Netherlands energy policy is largely decided at the “Tafel Grootschalige Energieopwekking” (Table for Large-scale Energy Production), a consultative body for the “Sociaal Economische Raad” (Social Economic Council). The parties that make up the “Tafel Grootschalige Energieopwekking” can therefore be considered major stakeholders in Dutch energy policy.

Next to these, other stakeholders exist who were also listed and described.

2.2.

This question was answered by interviewing representatives of what were considered to be the most important stakeholder groups. Which were most important to the decision making was decided in collaboration with the thesis-supervisors, based on what
secondary sources and interviewees agreed upon.

Experts in the field were interviewed primarily to support or disprove the theory, but also as stakeholders because getting the LFTR developed starts with them: if they cannot make a convincing case for the LFTR's feasibility, nobody is going to be persuaded to pursue the technology.

Because political will is essential for developing the LFTR, in addition to the experts, the most important stakeholder groups in the political decision making process were agreed to be:

- Politicians
- Anti-nuclear power/environmental protection lobby groups
- (Renewable) Energy producing companies
- Civil servants/ministries

As a representative of the “Politicians” stakeholder group, M. van der Werf, former member of the Dutch House of Representatives for the CDA (Christen Democratisch Appèl) and spokeswoman for energy matters, was interviewed.

As a representative of the “Anti-nuclear power/environmental protection lobby groups”, the World Information Service on Energy, an international network organisation that is strongly opposed to nuclear power, was interviewed. As another representative, Natuur & Milieu, an organisation promoting sustainability, was interviewed. Greenpeace, an environmental lobby group, was also approached but declined to be interviewed. Milieudefensie, an organisation representing environmental interests, was also approached for an interview but indicated that they had no specific knowledge about nuclear energy and recommended the World Information Service on Energy. Stichting Laka was also contacted but they stated that their stance on thorium was described in a document which was sent to the researcher. The document appeared not to be about the LFTR but about other types of thorium reactors and was sent to Dr. Kloosterman for further analysis.

As a representative of the “energy producing companies” stakeholder group, M. J. van Eijkelenburg, strategic director of Duurzame Energie Koepel, an organisation that represents the interests of the Dutch sustainable energy sector was interviewed.

As a representative of the “Civil servants/ministries” stakeholder group, the Ministry of Economic affairs was contacted. After explaining the research background and intentions an e-mail address was provided to direct a request for an interview to. In the e-mail the questions that needed to be answered were also included, and this yielded a very thorough reply that more than answered the questions that were going to be discussed in the interview. An actual interview was therewith deemed redundant.

2.2.3. Research question 3

**Research question 3**: “What is the significance of thorium fuelled nuclear power when generated in the Liquid Fluoride Thorium Reactor to (renewable) energy business models, and with that, to the IBS-lectoraat? Are there sufficient grounds to warrant further research into the subject?”

To answer research question 3 the secondary research backed-up by expert interviews described in research question 1 “What are the advantages and disadvantages of thorium fuelled nuclear power when generated in the LFTR compared to uranium fuelled nuclear power?” was used to assess whether the LFTR is technologically feasible and if so, to what extent the claims about its benefits are justified. If the LFTR would not be technologically feasible or its benefits would be strongly exaggerated, this could be grounds to dismiss the LFTR as a serious threat to (renewable) energy business models, making it of little significance to the IBS-lectoraat and removing the need for further research. If the LFTR is technologically feasible and its supposed benefits are likely to be real then the opposite would apply with regard to (renewable) energy business models, the IBS-lectoraat, and further research. The overview of stakeholders in the developments of thorium fuelled nuclear power as researched in research question 2 was used to further support and clarify these recommendations.
3 Basics

1.1. What is thorium fuelled nuclear power?

3.1. What is thorium?

Thorium is a chemical element. An element is a pure substance that is made up of only one type of atom. Examples of other elements are iron, copper, lead, uranium, etc. (TJNAF, 2013). Like uranium, thorium can be used to generate nuclear power. Atoms are made up of positively charged protons, negatively charged electrons, and neutrally charged neutrons. What kind of material an atom is, is decided by the amount of protons in the atom’s core, or nucleus, which gives the atom its atomic number (TJNAF, 2013). For example: an atom with 47 protons is an atom of silver, an atom with 79 protons is an atom of gold, and an atom with 80 protons is an atom of mercury (Winter, Mark, 2012). Thorium has 90 protons in its core, which is among the highest of all the elements. It is a silver-white, soft metal with properties somewhat similar to lead. It was discovered by Swedish chemist Jons Jacob Berzelius in 1828, who named it after the Norse god of thunder, Thor. 70 years later Marie Curie and Gerhard C. Schmidt established that thorium was a radioactive element (Bentor, 2013) (chemistryexplained.com, 2013).

3.2. What is radioactivity?

Some atoms have an unstable nucleus, which means the nucleus is prone to decomposition (falling apart) and forming nuclei with a higher stability. As it decomposes, energy and particles are released which we call radiation, and this process of decomposition is what we call radioactivity. There are 3 types of radiation: Alpha radiation, which consists of a stream of positively charged particles, Beta radiation, which consists of a stream of negatively charged electrons, and Gamma radiation which consists of high energy photons (light energy) (Helmenstine, 2013) (What is nuclear, 2013).

3.3. Nuclear fission & power generation

Nuclear fission, not to be confused with nuclear fusion, is the process at the core of nuclear energy production. The nucleus of an atom is hit with free neutrons and splits into smaller nuclei and more free neutrons, which in turn hit the nuclei of other atoms, causing a chain reaction. When a nucleus splits, a tremendous amount of energy is released which is used to make steam. The steam in turn is used to drive the turbines that produce electricity. In effect, a nuclear power plant is a high-tech steam engine connected to an electricity generator (University of Wisconsin, 2013) (World Nuclear Association, 2013).

3.4. Isotopes

Isotopes are different forms of the same element (same atomic number/protons in the core) with different amounts of neutrons, giving it slightly different properties (about.com, 2013). Examples are Uranium-233 and Uranium-232, both have 92 protons, but Uranium-233 has 141 neutrons and Uranium-232 has 140 (World Nuclear Association, 2012).

3.5. Elements turning into others: transmutation

When the nuclei of radioactive atoms emit radiation, they are emitting protons, neutrons, and electrons. Because they are left with fewer protons, neutrons, or electrons in their nucleus they change into a different isotope of the same element (different amount of neutrons), or even a different type of element (different amount of protons). Through this principle, the element thorium can actually change into the element uranium (Silva, 2013). Other examples of elements that thorium changes into during its decay chain are proactinium, neptunium, and plutonium (Hargraves & Moir, 2010, p. 306).

3.6. Molten Salt Reactors

The Liquid Fluoride Thorium Reactor (LFTF) is a type of Molten Salt Reactor (MSR). MSR’s are reactors that use a molten salt mixture for coolant, as a fuel, or both. When the MSR is referred to in this research therefore, it refers to the class of reactors that the LFTR’s belongs to (Touran, 2013).
4 The Liquid Fluoride Thorium Reactor (LFTR) vs. the Light Water Reactor (LWR)

The Liquid Fluoride Thorium Reactor is an innovative reactor design that uses liquid instead of solid fuel, and thorium instead of uranium. Its radically different design gives it very different properties from "traditional" reactors, some of which are believed to be considerable advantages. These will be described in more detail in following chapters.

4.1. The Light Water Reactor (LWR)

Most traditional nuclear reactors are Light Water Reactors (LWR’s) (The Nuclear Information Center, 2012). A LWR consists of a core of uranium-235 fuel rods surrounded by (pressurized) water. The uranium in the core undergoes fission, which generates free neutrons to keep the nuclear chain-reaction going, as well as large amounts of heat. The water surrounding the core acts as a coolant to ensure the core does not get too hot and “melts down”, and transports the heat generated in the core to a steam generator where water turned to steam powers the electricity generation (European Nuclear Society, 2013). The control rods consist of a neutron-absorbing material like cadmium, hafnium or boron and serve to control the rate of-, or stop the nuclear reaction in the core when necessary (World Nuclear Association, 2012).

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5 LWR’s can be subdivided into Pressurized Water Reactors (PWR’s) and Boiling Water Reactors (BWR’s). PWR’s use pressurized water to transfer heat to generate steam elsewhere, while BWR’s use the heat in the core to boil water and generate steam in the core.
4.2. The Liquid Fluoride Thorium Reactor (LFTR)

In a nutshell, the LFTR reactor design consists of a core and a “blanket”. Both hold a different mixture of molten salts and either thorium (blanket) or uranium (core). The uranium in the core serves to generate heat to produce steam for electricity generation, but also to turn the thorium in the blanket into that same uranium. The uranium undergoes fission, releasing neutrons that hit the thorium atoms and turn them into an isotope that decays (changes into) the same uranium that’s in the core. This is then chemically separated and transported to the core, to serve as nuclear fuel and to turn more thorium into uranium. Because the fuel is in liquid instead of solid form, it is much easier to separate out useful, as well as unwanted by-products, and to otherwise manipulate the fuel. This is a great advantage over solid fuel, which is difficult to manipulate once inside the reactor, and “traps” unwanted fission by-products inside its structure. (Hargraves & Moir, 2010, pp. 307,308) (LeBlanc, 2009, pp. 1644,1645) (Hart, 2011, p. 17).

The salt mixture considered to be optimal for use in the LFTR consists of lithium fluoride and beryllium fluoride (LiF-BeF$_2$), and is commonly referred to as “FLiBe”. It has a high boiling point of 1430°C (Ingersoll, et al., sd, p. 5) which enables it to remain liquid at high temperatures without turning to steam (Sohal, et al., 2010, p. 8). It also serves as a neutron moderator (Sorenson, 2012). A neutron moderator’s function is to slow down fast neutrons, because neutrons that are too fast are not useful for sustaining the nuclear chain reaction (Carpenter, 2003, p. 7).

This does mean however that the LFTR needs an installation to cleanse and maintain the FLiBe mixture, which runs parallel to the reactor component (Kloosterman, 2012).

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6 For a more detailed explanation see appendix D
7 see: Nuclear energy from thorium basics: transmutation
5 Supposed benefits

1.2. What are the advantages and disadvantages of LFTR reactor design compared to traditional nuclear reactor design?

There are those in the scientific community who claim that the LFTR’s design gives it some truly remarkable qualities that make it far better suited for power generation than traditional nuclear reactor designs like the LWR. The following represents their claims, which will be scrutinized in the “challenges” chapter of this report:

1) The thorium fuel-cycle produces far less nuclear waste than the uranium fuel-cycle, and 99.99% of waste that is produced only remains hazardous for about 300 years, which is a stark contrast to uranium’s tens- to hundreds of thousands of years. *(5.1. Cleaner)*

2) Because of the LFTR’s design, the chance of nuclear meltdown and/or explosion is effectively eliminated. *(5.2. Safer)*

3) There is much more thorium on the planet than uranium. It is estimated that uranium has the potential to power the world for another 100-230 years, while thorium reserves can power the world for tens of thousands of years. *(5.3. More)*

4) LFTR energy production is believed to be cheaper than LWR energy production. *(5.4. Cheaper)*

5) Thorium is less suited for use in nuclear weapons than uranium. *(5.5. Decreased proliferation danger)*

6) The thorium fuel cycle produces rare isotopes that have important medical applications. *(5.6. Medical)*
5.1. Cleaner

The advantages of nuclear power come at a hefty environmental cost. Tons (NEI, 2013) of nuclear waste is produced that is so toxic it has to be stored in a contained location for tens-, possibly hundreds of thousands of years, and a satisfactory solution for this waste is yet to be found (Genyk, 2013). To many, this is the most compelling argument against nuclear energy and rightly so: we are irresponsibly producing highly toxic material that we do not know what to do with, passing the problem on to future generations.

There is a marked difference between the traditional solid uranium fuel power generation process and the liquid fluoride thorium process however. The latter is much more efficient at converting fuel into energy, and produces a fraction of its waste, almost all of which remains hazardous for a much shorter time than the uranium fuel-cycle’s waste (Hargraves & Moir, 2010, pp. 309, 311) (Juhasz, et al., 2009, p. 4).

5.1.1. The Light Water Reactor (LWR)

Traditional uranium fuelled reactors are not very efficient when converting uranium into energy. One reason for this is that the heat and radiation that is released in the reactor core damages the solid uranium fuel rods, which causes them to have to be taken out after just a few years and only having consumed 3-5% of the rod’s energy potential. Another reason energy production is slowed, is the build-up of fission by-products within the fuel rod, such as the gas xenon-135. Xenon-135 has a great propensity for absorbing free neutrons, which disrupts the chain reaction of the fission process, because neutrons that are absorbed will not hit the nuclei of other atoms. The remaining damaged part of the uranium fuel rods together with fission by-products in the form of long-lived transuranic materials such as plutonium, americium, neptunium and curium, are all nuclear waste that has to be stored for at least tens of thousands of years (Hargraves & Moir, 2010, p. 305).

5.1.2. The LFTR

The liquid fluoride of the LFTR does not suffer from radiation damage due to its strong ionic bonds. Because of this, the fuel does not have to be removed before all of it has been used, and any fission by-products that are formed can remain in the fuel as well until they too undergo fission and are burned up (Hargraves & Moir, 2010, p. 308) (Hart, 2011, p. 17).

In the traditional solid fuel design fission by-products are trapped inside the fuel material, while in liquid fuel, by-products can be relatively easily extracted. Xenon, the gas that disrupts the chain reaction of the fission process for example simply bubbles out of the liquid fuel solution (Hargraves & Moir, 2010, p. 308) (LeBlanc, 2009, p. 1645) (Kloosterman, 2013).

What is more, the LFTR/MSR can even be used to burn existing nuclear waste (LeBlanc, 2009, p. 1645). One such design, the Waste Annihilating Molten Salt Reactor (WAMSR) has already been developed and patented by Trans Atomic Power (Martin, 2012) (Transatomicpower, 2012).
5.1.3. Conversion rate

The LFTR is much more efficient at converting thorium into energy than the LWR because all of the fuel is burned up, and the thermal- to electrical energy conversion rate is 45-50% instead of 30-35% (Juhasz, et al., 2009, p. 4) (Hargraves & Moir, 2010, p. 311).

The figure below gives a comparison between the amounts of raw material needed- and waste production for the traditional uranium/Light Water Reactor (LWR) fuel cycle and the thorium/LFTR fuel cycle to produce the same amount of energy.

If the traditional uranium/LWR fuel cycle starts with 250 tons of uranium, 35 tons of enriched uranium containing 1.15 tons of useful uranium-235 is extracted from this. What comes out on the other end as radioactive waste is 35 tons of fuel containing 33.4 tons of uranium-238, 0.3 tons of uranium-235, 1 ton of fission by-products and 0.3 tons of plutonium (Hargraves & Moir, 2010, p. 308).

In the thorium fuel cycle 1 ton of thorium is used in its entirety and what comes out on the other end is a ton of fission products, 83% of which are stable\(^8\) in only 10 years, another 17% in approximately 300 years, and 0.0001 tons of plutonium, which needs to be stored for a very long time (Hargraves & Moir, 2010, p. 308) (Juhasz, et al., 2009, p. 4). **Authors note: For a 1000MW plant, this would come down to 100 grams of plutonium waste a year\(^9\), compared to “(...) up to 290 kilograms of plutonium” a year for LWR’s.** (World Nuclear Association, 2012)

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\(^8\) Stable means that it has reached the same radiation levels as when it was still in the earth. It could in theory be put back without exposing the environment to extra radiation. (Kloosterman, 2013)

\(^9\) Confirmed by (Kloosterman, 2013)
5.2. Safer

Another major argument against the use of nuclear power is the risk of a reactor exploding, melting down, or otherwise releasing radioactive material into the environment. What many people do not realise however, is that while meltdown and release of radioactive material are valid concerns, nuclear explosion is not. The only type explosion that is likely to occur is a steam explosion, which is what happened to the Chernobyl reactor in 1986. Although a serious disaster, it is much less destructive than an actual nuclear explosion (Wilkins, 2011). Due to the nature of liquid fluoride thorium fuel and LFTR design the risk of a steam explosion or meltdown is effectively eliminated.

5.2.1 LWR

5.2.1.1. Steam explosion

The most volatile aspect of nearly all reactors in operation worldwide is the pressurized water. Next to serving as the coolant, and neutron moderator, it is turned into steam by heat from the fission in the core to drive the turbines and generate electricity. The water is kept at very high pressure to raise its boiling temperature, so it can reach a higher temperature (and carry more thermal energy), without turning into steam (Hargraves & Moir, 2010, p. 310). If the pressurized coolant water escapes, a steam explosion occurs. The high pressure “artificially” increased the water’s boiling temperature, so when this pressure is lost its boiling temperature suddenly drops. Water that remained liquid at a temperature far above 100 °C before, now turns to steam instantly at its present temperature, causing it to expand greatly and creating an explosive reaction. To prevent a pressure explosion, the high pressure needs to be contained, which is achieved by a system of highly engineered, highly expensive piping and pressure vessels called “the pressure boundary”. If the pressure boundary were to fail, reactors are equipped with a huge concrete dome constructed to contain a steam explosion (Hargraves & Moir, 2010, p. 310) (LeBlanc, 2009, p. 1645).

5.2.1.2 Meltdown

So what is meltdown exactly? The nuclear fuel in the reactor core needs to be cooled so temperatures are kept within limits, which is done by pumping coolant water to the core. When the reactor has to be shut down in an emergency, the nature of the nuclear material in the core causes it to keep reacting even though power has been shut off. Pumping coolant water is then taken over by emergency backup generators, but if these fail, the heat in the core will boil off all the water surrounding it. This eventually exposes the nuclear fuel, which then reaches very high temperatures and melts, hence meltdown. This highly radioactive molten fuel then has the potential to burn through the protective layers of steel surrounding the core and be released into the outside environment, with obvious dire consequences (Matson, 2011) (Gamble, 2011).
5.2.2. The LFTR

5.2.2.1. Steam explosion

Contrary to traditional reactors, the LFTR coolant (liquid fluoride salt) does not have to be kept under pressure because it does not boil below 1400 °C, thus eliminating the threat of a pressure explosion. If a disruption in a transport line would occur this would result in a leak instead of a steam explosion. The fluid leaking from the line would simply be captured in a catch basin where it would passively cool and harden (Hargraves & Moir, 2010, p. 310) (LeBlanc, 2009, p. 1644).

5.2.2.2. Meltdown

Because the molten salt mixture in the LFTR is already in molten state, “meltdown” as seen in LWR’s is no longer an issue. In case of a hypothetical runaway reaction, temperatures could increase but this would only potentially damage the steel containing the salt mixture (Kloosterman, 2013). To protect against unwanted temperature increases the LFTR has other safety features.

5.2.2.3. Negative temperature coefficient of reactivity

A LFTR safety feature that it shares with all of the new generation of Light Water Reactors is the “Negative temperature coefficient of reactivity”, which has virtually eliminated the risk of meltdown in LWR’s. Modern nuclear fuels like liquid fluoride thorium have been engineered to be self-limiting in case control over the reactor is lost. When the temperature in a reactor rises beyond a certain level, (indicating that control is lost/a power excursion), the fuel will expand, which reduces the effective area for neutron absorption. This automatically decreases the rate of fission, thus acting as a self-limiting property of the fuel itself which requires no human intervention/ manipulation (Hargraves & Moir, 2010, p. 310) (LeBlanc, 2009, p. 1645) (Juhasz, et al., 2009, p. 4).

5.2.2.4. Frozen salt plug

Another simple yet effective safety feature of the LFTR is a plug at the lowest point of its piping system, made from frozen salt. The plug is kept frozen by being cooled by a fan. When temperature rises too high or power to the reactor (and the fan) is lost, the plug will melt and the liquid fluoride fuel simply pours out of the core and into a safe containment basin (Hargraves & Moir, 2010, p. 310) (LeBlanc, 2009, p. 1644) (Juhasz, et al., 2009, p. 3).

The big difference with earlier solid fuel designs here is that instead of power being needed to shut down a reactor safely, power is needed to prevent the safe shutdown of a reactor. Therefore, in case control is lost the only logical outcome is automatic shutdown.
5.3. More

There is a lot of thorium on our planet.

Thorium can be found in most rocks and soils. Soil commonly contains about 6 parts per million of thorium, making it 3-4 times more abundant than uranium (LeBlanc, 2009, p. 1645) (World Nuclear Association, 2012), and it is more easily extracted (Hargraves & Moir, 2010, p. 306).

Total world thorium resources are estimated to be 5.4MLN tonnes (World Nuclear Association, 2013) over half of which can be found in India, Turkey, Brazil and Australia. ¹⁰

This is enough to power the entire world for tens of thousands of years (Kloosterman, 2012) (Juhasz, et al., 2009, p. 5). Although not infinitely sustainable, this is a very long time compared to the roughly 100 (Foro Nuclear, 2011) (National Nuclear Laboratory, 2012, p. 11) to 230 years (Fetter, 2009) that uranium has to offer. ¹¹

Should one wonder why thorium has the potential to power the world 67, to a 100+ times longer than uranium, while there is just 3-4 times more of it, this is because you get a much higher energy yield from thorium, than you would from an equal amount of uranium (Hargraves & Moir, 2010, p. 311) (Juhasz, et al., 2009, p. 4).

¹⁰ For estimated world thorium resources see appendix D

¹¹ This estimate is at the present rate of consumption and might be influenced by and increased demand for uranium or more efficient uranium burning reactor designs.
5.4. Cheaper

In addition to being much cleaner, safer, and suited for long term energy production, the LFTR might also be cheaper than traditional nuclear energy and possibly even coal.

The MIT study “The Future of Nuclear Power” (Deutch, et al., 2009, p. 6) puts capital costs for coal plants at $2.30 per watt and nuclear power at $4.00 per watt. An important reason for the higher costs of nuclear power is the high fixed costs involved in nuclear power plant construction. Traditional designs need a large concrete dome constructed to accommodate for large amounts of cooling water flashing to steam in an instant causing a pressure explosion, in case of a pressure breach. The LFTR operates at atmospheric pressure and contains no pressurized water, so it might not need a dome. For the LFTR a much more close-fitting structure could suffice: one concept is a hardened concrete facility below ground with a protective concrete lid on ground level to protect it from aircraft impact and other possible forms of assault (Hargraves & Moir, 2010, pp. 310, 311).

Other factors adding to a lower cost profile are that the LFTR can do without expensive coolant injection systems, lower fuel costs (thorium instead of uranium, no need for fuel element fabrication), simpler fuel handling (liquid fuel, no periodic shutdowns needed to replace solid fuel elements), smaller components, and a much higher energy efficiency (Hargraves & Moir, 2010, p. 311).

LFTRs operate at around 800 °C. This temperature is favourable for conversion of thermal to electrical energy, which causes the LFTR to reach a conversion efficiency of 45%-50+% instead of the 33% typical for coal and traditional nuclear power plants (Hargraves & Moir, 2010, p. 311) (Juhasz, et al., 2009, p. 4). The high temperature also allows for excess heat to be used for driving other industrial chemical processes such as hydrogen production, among others. Because of its compact size and safe design, excess heat could even be used to heat homes and offices situated nearby (Hargraves & Moir, 2010, p. 311).

Because of its size and design, it seems reasonable that 100 megawatt LFTRs could be produced in factories for around $200 million apiece, similar to the way Boeing produces large aircraft in factories. Westinghouse already produces modular nuclear power plants, the AP1000 Advanced Pressurized Reactor can be built in 36 months from the first pouring of concrete. Such a standardized production process would drive unit costs down further (Hargraves & Moir, 2010, p. 311).

Mass produced LFTRs could even replace the power generation components in existing fossil fuel powered plants, integrating with the existing electrical distribution infrastructure which would also save huge amounts of money (Hargraves & Moir, 2010, p. 311).
5.5. Decreased proliferation danger

It is said that although possible, thorium is an unlikely candidate for use in nuclear weapons, reducing the danger of nuclear material being diverted from a reactor for use in bombs.

The uranium-233 that is produced from thorium-232 is always accompanied by uranium-232, which acts as a proliferation prophylactic: Uranium-232 is chemically identical and essentially inseparable from uranium-233. It produces strong gamma-radiation (Hart, 2011, pp. 9,10) (Juhasz, et al., 2009, p. 4) that is easily detectable and highly destructive to ordnance components, circuitry, and especially human beings (Hargraves & Moir, 2010, p. 312).

Another reason has to do with the amount of free neutrons that are produced in the LFTR core. When uranium-233 absorbs a neutron, fission occurs and just over 2 new free neutrons are released. 1 is used to drive a subsequent fission by being absorbed by another uranium-233 atom and sustain the chain reaction, and one to convert thorium-232 to uranium-233. A well-designed LFTR therefore creates just enough neutrons to generate fuel, but no more. If meaningful quantities of uranium-233 would be stolen, power generation would wind down which would certainly be noticed (Hargraves & Moir, 2010, p. 312).

Only if the reactor was actually controlled by the party trying to use it for siphoning off nuclear weapons material could such a thing go unnoticed, and a party with such power would have a much easier time just enriching natural uranium or generating plutonium (Hargraves & Moir, 2010, p. 312) (Kloosterman, 2013).

The LFTR can even be used to deal with the plutonium from decommissioned nuclear weaponry. It can be added to the salt mixture where it is used for energy and broken down into rest-products that are unsuited for use in nuclear weapons (Rooyen, 2011) (Hart, 2011, p. 10).
5.6. Medical

The Uranium-233 decay-chain produces certain isotopes that have been extinct, meaning that they do not occur in nature any longer. They existed at one time but have long since decayed into other isotopes, and can now only be produced artificially with the help of installations like the LFTR.

These isotopes, such as bismuth-213, are expected to be much more efficient at fighting cancer than what is being used now. First, because they emit Alpha-, rather than Beta-radiation which can target cancer cells more precisely and secondly because bismuth-213 is only one decay away from the end of its decay-chain, so it will not remain in the body while decaying further and emitting more radiation (thoriumremix2011, 2011) (Energy From Thorium Foundation, 2012).
6 History

1.3. Why is thorium not being used as a fuel today?

After reading about the benefits that thorium supposedly has, the question that presents itself is “if thorium really is much better suited for generating nuclear power, why is it not being used today?” The answer to this question lies in choices made in the early days of nuclear power research.

Different methods of nuclear power generation require different approaches, different machinery, and different research. There are many hundreds of different combinations of type of fuel, type of coolant, type of moderator, and type of fissile material. Because of that, a decision had to be made at one point about which combination to invest huge amounts of time, manpower, and funding in, and which to sideline. The fissile material that made the cut was uranium. There were a number of reasons for this but what sealed the deal was the then director of America’s naval reactors admiral Hyman Rickover. He decided in the 1950’s that solid uranium oxide enriched in uranium-235 and using water as a coolant and moderator was most suitable for powering the first nuclear submarines, because it was likeliest to be ready soonest, and possibly even more significant was that this fuel cycle would create plutonium-239 as a by-product, which was needed for developing nuclear weapons. From then on the vast majority of (research, manpower, funding and other) resources were allocated to the development of solid uranium fuel reactors. This led to the current situation in which solid uranium fuel reactors have a huge advantage over certain other types of fuel/reactor combinations such as the LFTR. Solid uranium as a nuclear fuel is much better understood, and the entire infrastructure surrounding nuclear power production is developed to accommodate it. This represents very large amounts of resources and time that innovative technology like the LFTR has to catch up with (Hargraves & Moir, 2010, pp. 304,305).

A Molten Salt (test) Reactor has been in operation in Oak Ridge National Laboratories during the 1960’s: the Molten Salt Reactor Experiment (MSRE). It ran for almost 5 years and results of these tests were highly successful, (LeBlanc, 2009, p. 1646) but the program was finally terminated due to budgetary reasons (Energy from Thorium Foundation, 2012).

One might wonder why alternatives to solid uranium have not also been further developed when their potential became known, and the answer to this is that Governments and companies have simply not been willing to take a chance on developing a technology that will take many years and large investments to mature, just like they are not today. Besides that, the old technology to many seemed -and still seems- perfectly adequate. Uranium does the job and will be around for at least another century, and even the nuclear waste issue is not a deal breaker to everyone. This was even truer several decades ago, when environmental issues like CO₂ output were not as big an issue, and the nuclear weapons argument was opposite to what it is today: governments needed the uranium-235 and plutonium-239 (Atomic Archive, 2013) for constructing nuclear weapons, while we are shifting in a direction of deproliferation today (Hargraves & Moir, 2010, pp. 312,313).
7 Challenges

If we were to accept the theory above it sounds like the LFTR has nothing but advantages compared to the LWR, and even invalidates some of the major arguments against nuclear power. But how certain are the claims that are being made about thorium as a nuclear fuel? Is the theory sound and if so, will practice turn out to be as the theory predicts? Which factors if any are still uncertain and what is being done to solve it? The most important challenges to developing the LFTR are discussed here.

7.1. Continuous cleansing/manipulation of liquid fluoride mixture (FLiBe)

The liquid fluoride fuel mixture, or FLiBe, is a key LFTR characteristic. It allows the LFTR to convert virtually all of the by-products that come into existence as a result of the thorium decay cycle into energy and can be manipulated much easier than solid fuel, to separate wanted and unwanted fission products out. The processes to achieve this are currently still being developed so this is a hurdle yet to be taken.

For cleaning/manipulation to be possible, the LFTR requires a chemical processing installation parallel to the nuclear power reactor. Although cleansing of fuel was also part of the Molten Salt Reactor Experiment that ran in Oak Ridge in the 1960’s, this was achieved in a separate installation and happened by the batch rather than continuously, which is what is required in the current LFTR design (Kloosterman, 2013).

That does not mean this is an insurmountable obstacle. Many of the processes that are likely to have to be employed are familiar technology and routinely used in other industries like aluminium production. Time, funding and research are needed to work out what is needed to build the chemical processing installation, but both Dr. Kloosterman and the see no reason to assume solutions cannot be developed. Even if obstacles arise that are very impractical or difficult, these can probably be worked around by using a slightly different approach. A more relevant question is whether workarounds will prove so complex that they make the design too costly.

One way of removing unwanted fission by-products that is currently being researched, is through the use of a process called “helium bubbling”, a technique where helium gas is led through the salt mixture, “pushing” solid particles of fission by-products out of the salt mixture (Kloosterman, 2013) (Nuclear Chemistry Expert, 2013).
7.2. Material

Another point of interest is the material that is to be used for containing the liquid fluoride mixture. The mixture is very toxic, corrosive, hot, and radioactive, requiring a metal that is able to withstand all of these influences for years.

The material that was used in the Oak Ridge Molten Salt Reactor Experiment was the incredible durable alloy “Hastelloy-N”. Apart from some minor adjustments to the material to improve its radiation resistance that were made later, the alloy performed satisfactorily (Kloosterman, 2013) (LeBlanc, 2009, p. 1644).

Modern increased safety measures will likely require renewed rigorous testing but a suitable metal can probably be found. The question again is whether having to use a special alloy will lead to much higher costs, but J.L. Dr. Kloosterman and “Nuclear chemistry expert” were of the opinion that this would not be the case. Material costs might increase somewhat because of the use of an expensive alloy, but because the LFTR is not under pressure, piping and other containment vessel walls can be much thinner than with traditional reactors, which reduces the amount of metal required.

7.3. Beryllium

FLiBe contains the element beryllium, which is a highly toxic carcinogen. It therefore requires careful handling, and fool proof containment. This is routinely done in industries like aluminium production so it is possible, but it will raise security requirements and increase overall complexity. This is why using an alternative to beryllium might be desirable (Nuclear Chemistry Expert, 2013) (LeBlanc, 2009, vp. 1655). A possibility is lithium fluoride-thorium fluoride, which increases the melting point a little but also has additional benefits (Merle-Lucotte, et al., 2012, p. 2).

7.4. Graphite

The graphite that serves as a moderator and neutron reflector in the LFTR can get damaged under the influence of fast neutrons (Kasten, 1969, p. 1). Because of this it has to be refreshed once every 20 years, and damaged graphite needs to be stored. It is not very radioactive but still not fit for human contact and has to be buried (Kloosterman, 2013).

7.5. Start-up fuel

If LFTR’s are to be used on a large scale, considerable amounts of fissile uranium-233 are needed to start the thorium chain reaction. Currently there is not enough uranium-233 to meet this demand (LeBlanc, 2009, p. 1652). This problem can be solved by using uranium-235 or plutonium-239 (Kloosterman, 2013).

7.6. Time

Because research still has to be done into the chemical processing installation, materials, reactor safety, and regulatory aspects it will take another 15 years to build a demonstration reactor and another 5 years (so: 20 from now) to build commercial ones. This is regardless of the fact that a test reactor was operational in Oak Ridge in the 1960’s: changed (regulatory, material) circumstances and technology like the chemical processing installation simply require a lot of time. 15-20 years is under the best of conditions, meaning with sufficient funding and manpower. Increasing the amount of funding and manpower would probably not influence the development time much (Kloosterman, 2013).

Due to the long development time and the uncertainties that need more research it is hard to find parties willing to invest time and resources. More on this in “cost effectiveness”.

48
The Chinese government is one of the few governments that do seem to have this long-term vision. China is leading the way in Molten Salt Reactor development, in 2011 they announced their intention of developing a thorium based molten salt reactor in 20 years (news356.com, 2011). The project is headed by Jiang Mianheng, son of the former Chinese president Jiang Zemin and has a start-up budget of $350MLN, and 140 PhD scientists working on it. This number is to be increased to 750 scientists by 2015 (Pritchard, 2013).

Contrary to Europe, China does not have Europe's problem of having to take other member states' opinions into account when starting large projects like this. If government decides a technology is worth pursuing, funding and manpower is found. It could be that they are simply exploring every type of energy technology because they have the resources for it and need a solution for their huge energy need (Kloosterman, 2013).

7.7. Cost-effectiveness

A major question that still needs to be answered is whether the LFTR will turn out to be cost-effective.

According to Hargraves and Moir the LFTR could be much cheaper\(^\text{13}\) than traditional designs like the Light Water reactor but there are others like Dr. Kloosterman who say that although this might be true, more research is needed before such claims can be reasonably made. What is more, Dr. Kloosterman doubts whether the argument that the costs saved by not having to construct a concrete dome will really result in the drastic amount of savings that Hargraves and Moir attribute to it.

Because of the uncertainty of its cost effectiveness and the long period of research still needed, governments and companies are not eager to invest in the technology. It will take at least another 15 years, and Kirk Sorenson of FliBe energy estimates that research costs will be about a billion dollars (thoriumremix2011, 2011).

Governments usually do not have a long term vision that goes far beyond their 4 year term, and are unwilling to invest in something that is not yet proven to perform as theory predicts, especially when it has to do with unpopular nuclear power. Local and national European governments also do not have the resources available to make the large investments required in these times of crisis. The most suitable candidate for developing this technology would be the European Union, but as they have to take the opinions of member states that want to have nothing to do with anything related to nuclear fission into account, such as Germany, Denmark and Austria this is not likely to happen. What is peculiar is that the EU does invest large amounts of time and resources into developing nuclear fusion, another alternative to uranium fuelled nuclear power that would have great energy-, radiation-, and waste advantages, (Freudenrich, 2013) but one that is far less likely to ever be feasible than the LFTR. The reason for this is that nuclear fusion is easier to defend to their constituencies (Kloosterman, 2013) (van der Werf, 2013).

7.7.1. LFTR costs

Researchers working on the Molten Salt Reactor Experiment (MSRE) at Oak Ridge National laboratories prepared a detailed cost breakdown and description for a conceptual design of a 1000-MW (electric) Molten Salt Reactor in 1978. This estimate was later translated into the MSR's cost of electricity in 2001 by Dr. Ralph Moir Ph.D ScD.

Total costs came to (in year 2000 dollars) $1584MLN for the MSR, $1448MLN for the Pressurised Water Reactor, and $1106MLN for coal plants. This translates to a cost of electricity of 3.84 cents/kWh for the MSR, 4.11 cents/kWh for the PWR, and 4.19 cents/kWh for coal plants, which would make the MSR the cheapest form of electricity generation (Moir, 2001, p. 94).
Because the precise details of certain aspects of the LFTR still require more research however, it is uncertain how expensive the LFTR will turn out to be. If they lead to a very complex design the chance exists that the reactor will not produce cheaper electricity, although Dr. Kloosterman does expect the reactor to turn out relatively simple in its design (Kloosterman, 2013).

One such aspect is the chemical processing installation. It is not clear from the 1978 estimate which entry represents its costs, but this installation alone is estimated to cost a couple hundred million euros at least. It might be possible for a few reactors to share one chemical processing installation however (Nuclear Chemistry Expert, 2013).

The uncertainty of the 1978 estimate is also recognized by Dr. Ralph Moir:

“The information in this note is based on the three options as defined in 1978 and does not include current safety, licensing, and environmental standards, which will impact costs, as will CO2 sequestering and increased hazardous air pollutants for coal.” (Moir, 2001, P. 94)

A major argument for the LFTR being cheaper than traditional designs is that due to it not being under pressure, no large concrete dome has to be constructed to protect against a gas explosion. Although Dr. Kloosterman agrees that concrete represents the highest costs in nuclear reactor construction, he thinks this is not necessarily true. The reactor still needs to be protected against external attacks, requiring a substantial protective concrete structure to be built. A suggestion that is made to solve this problem without having to build the dome, is building the LFTR underground. A thick concrete slab on top would then suffice as protection from attack from the outside. The question then, is what extra costs digging in a reactor would add. This also sounds like a serious feat of engineering that might not come cheap, especially on difficult ground like very rocky or -soft terrain (Kloosterman, 2013).

Another point mentioned by M. Eijkelenburg, director of strategy at Duurzame Energie Koepe®, is that when calculating costs for nuclear energy plants, one should also calculate the costs for disasters and accidents. Explosions and meltdown
are not likely but the LFTR still produces nuclear waste and if it were to contaminate the environment this would represent significant costs (Eijkelenburg, 2013).

Authors note: this would then also have to be required for activities like deep-sea oil drilling.

7.8. Proliferation

With regards to proliferation, the LFTR would make illicit diversion of nuclear material by ill-willing third parties for use in weapons unlikely, but it would not make production of nuclear weaponry impossible. If a government with the capabilities to build a LFTR would want to use it for nuclear weapons manufacturing they could, but they would have a far easier time using the uranium-cycle to produce plutonium or highly enriched uranium (Kloosterman, 2013) (Hargraves & Moir, 2010, p. 312) (Hart, 2011, pp. 9,10).

According to an article in Nature, there even is a relatively easy path to produce enough uranium-233 to build a nuclear weapon for parties with access to modest nuclear facilities. Radiating freshly dug thorium-232 with neutrons for a month and then chemically treating it would do it (Dijkgraaf, 2012) (Ashley, et al., 2012). Authors note: Thorium is very abundant and probably not difficult to obtain, so this is something that could be done regardless of there being a LFTR.

7.9. Competing reactor designs

The LFTR is not the only innovative reactor design out there. Other designs are being developed that share LFTR characteristics:

**Fast Neutron Reactor**

Fast neutron reactors could be capable of converting 50 times more uranium into energy than is currently achieved, and produce less waste. The main problem with fast neutron reactors is that they are not cost-effective. Dr. Kloosterman argues that we have been trying to make them cost-effective for 20 years without success, so it might be time to try something else (Kloosterman, 2013) (Debusschere, 2013, p. 11).

**Waste Annihilating Molten Salt Reactor (WAMSR)**

2 Massachusetts Institute of Technology (MIT) students have developed an improved version of the LFTR called the Waste Annihilating Molten Salt Reactor (WAMSR). As the name suggests, the reactor runs on old nuclear waste and turns it into energy and a fraction of the original waste, that is safe after a couple of hundreds of years, but being a molten salt reactor it could also run on thorium. The company expects commercial reactors to come online in 20 years. It does not intend to build reactors themselves but to license its technology (Martin, 2012) (Transatomicpower, 2012).

**Traveling Wave Reactor**

The Traveling Wave Reactor is another innovative reactor design introduced by Intellectual Ventures. It could go for decades or possibly even hundreds of year without having to be refuelled. It runs on a little amount of Uranium-235, but mostly on Uranium-238 which is now considered to be a waste product (Wald, 2009). Bill gates, founder of Microsoft invested in a venture developing this technology, Terrapower (International Thorium Energy Organisation, 2010).

**High Temperature Reactor (HTR)**

The HTR is a reactor type that shares the inherent safety of the LFTR, but not its waste benefit because it uses solid uranium (Kloosterman, 2013).
8 Stakeholders

2. Who are the stakeholders in the development of thorium fuelled nuclear power?

If the claims about thorium fuelled nuclear power and the LFTR’s benefits are as good as they sound, the question is why more is not being done to develop this technology. The reason that’s given for it being side-lined in the past has to do with the history of nuclear power development, but it does not yet fully explain why it is not being picked up again today. If a comprehensive picture is painted as to who or what the forces are that exert influence over- or are influenced by the development of this technology, it might be better understood what is keeping it from being developed and what could be done to influence this.

Included in the list of stakeholders in the development of thorium fuelled nuclear power were those individuals, groups, organisations, or entities that either have considerable influence on the decision making process, or are considerably affected by the development of thorium fuelled nuclear power. What constitutes “considerable” was left to the researcher’s judgment, but should a reasonable claim to the unjust exclusion of a stakeholder (group) be put forward then this will be taken into consideration and added if found justified, to ensure an inclusion of any relevant stakeholder(group).

International stakeholders are discussed, but emphasis is placed on stakeholders in the Netherlands. In the question of thorium fuelled nuclear power transnational thinking is essential because of the amount of resources and political will required, but as this research was conducted in the Netherlands it was decided to identify stakeholders in this country as a way of limiting scope, and to serve as a general model for doing the same in other nations.

A list of stakeholders has been created that includes a brief description of the stakeholder in question, and their stake in this issue. The complete list with descriptions and references can be found in appendix E, but for the sake of brevity a compressed version is displayed here.

The natural environment

Nuclear waste is notorious for impacting the natural environment. The LFTR might be seen as yet another nuclear pollutant, or as an opportunity to reduce waste.

The (energy)-economy

If the LFTR produces cheaper electricity with less waste for tens of thousand of years, this will have a great impact on the economy. Almost every business and consumer requires electricity in some form or other.

Future generations

The decisions we make today impact those inhabiting the earth after us. The LFTR could have a positive or a negative impact, depending on how perceive this technology.
Citizens

Citizens can benefit from the LFTR’s advantages and suffer from its downsides. In democracies, their opinion also exerts influence on decisionmaking.

Scientists

Scientists are responsible for developing the technology.

Research institutions/universities

This type of research requires a large coordinated effort, which is why research is likely to take place at research institutions and universities.

Government

Because of the large amounts of resources needed, support for developing the technology probably has to come from (national) government, or a collaboration of governments. As a part of the government, politicians and civil servants are important stakeholders as well. In the Netherlands, energy policy is made at the “Table for Industry, large-scale energy production and Emission Trading Systems” (Tafel Industrie, grootschalige energieproductie en ETS), a consultative body for representatives of umbrella organisations that have a say in energy matters, from energy producers to lobby groups. Stakeholders in Dutch energy policy are the organisations represented at this “table”.

Companies

Energy producers like renewables, nuclear, oil, coal, and gas might suffer serious competition from the LFTR, if it does indeed turn out to produce cheaper electricity than they do. If it is perceived as “green” enough by the general public, it will be especially threatening to renewables.

It would also open up a whole new sector to do with thorium production, as well as present a great threat to the existing uranium industry.

6 companies that are currently developing thorium nuclear power have been identified: Flibe energy, Thor energy, Thorium Power Canada inc., Thorium Energy Generation Pty. Ltd, Trans-atomic Power, and Lightbridge.

Potential private sector financiers

Both Google inc., and Bill Gates, founder of Microsoft, have shown interest in thorium based nuclear power.

Thorium developing countries

Countries that are currently developing thorium are India, China, the U.S., Norway, Japan, France, and Russia.

Lobby groups

Lobby groups against nuclear power in the Netherlands are Greenpeace, the World Information Service on Energy, and Stichting Laka. Two important international pro-thorium organisations are the Energy from Thorium foundation, and the International Thorium Energy Organisation (IThEO).

Military

The military might be interested in the power the LFTR produces and its ability to be produced in compact units, but might not want to move away from uranium because of its use in nuclear weaponry.

Press

One of the main issues with the development of thorium fuelled nuclear power is that people do not seem to be aware of its possibilities. The press is a very important stakeholder because they can be instrumental in spreading information.
9 Conclusion/recommendations

Research question 3: “What is the significance of thorium fuelled nuclear power when generated in the Liquid Fluoride Thorium Reactor to (renewable) energy business models, and with that, to the IBS-lectoraat? Are there sufficient grounds to warrant further research into the subject?” will be answered in this chapter.

9.1. Findings & conclusion

9.1.1. Research question 1: LFTR advantages & disadvantages

Due to the explorative nature of this research, making claims as to the definite and irrefutable benefits of the LFTR would be presumptuous, as would be claims of the opposite. Nonetheless, a comprehensive overview is presented of what thorium fuelled power in the LFTR is and what it could possibly become. When combining the LFTR’s supposed benefits and its challenges, there is nothing that suggests that what is claimed about the LFTR technology is gravely overestimated or impossible, and if practice turns out as theory predicts this technology could well be very important.

Waste

In terms of its waste profile the LFTR is much cleaner than the Light Water Reactor. It produces 35 times less radioactive waste than the LWR. 83% of that waste is stable after 10 years, 17% after 300 years, and 0.01% is traditional long lived nuclear waste that has to be stored for a very long time. In a 1000MW reactor that would amount to 100 grams of plutonium a year, compared to up to 290 KG’s for LWR’s.

14 See: 5.1. Cleaner

Safety

The LFTR therefore is nuclear power with greatly reduced waste, but not entirely without. One could argue that any nuclear waste is too much nuclear waste, but it certainly is a significant improvement compared to what we have now. Realistically, investments in nuclear power are going to continue to be made, so perhaps lobbying for cleaner technology would be strategic.

What is more, Molten Salt Reactors can even be built to run on existing nuclear waste, creating an opportunity to solve the current waste problem. The Waste Annihilating Molten Salt Reactor (WAMSR) turns nuclear waste into energy and greatly reduced, safer waste.

15 See: 5.2. Safer

The LFTR design is such that the reactor is inherently safe. Meltdown and gas explosion, the two main dangers of LWR’s, are not an issue anymore due to its radically different design. As further layers of protection the LFTR has a negative temperature coefficient of reactivity, which automatically decreases the rate of fission when the temperature rises, and a frozen salt plug in the lowest point of its piping system that melts automatically when power is lost, allowing the molten salt liquid to drain into a safe containment basin.
The molten salt mixture is an incredibly toxic, corrosive, hot, and radioactive liquid however. We will just have to rely on the experts to effectively contain it, which is something that is possible in theory and is routinely done with similar substances in other industries. The beryllium it contains is a potent carcinogen. It can be handled safely but this would mean increased safety requirements which could lead to an increased complexity. It might therefore be desirable to use a substitute, which exists.

The improved safety is not unique to the LFTR however. Other reactor designs are said to be inherently safe, making this benefit somewhat less pronounced\(^\text{16}\).

More\(^\text{17}\)

There is a lot of thorium on our planet, enough to provide the entire world with electricity for tens of thousands of years. Although not infinitely sustainable, this is a great difference with the 100-230 years of uranium that is left, at the present rate of consumption.

Cheaper\(^\text{18}\)

The LFTR is claimed to produce cheaper electricity than LWR's and possibly even coal. Although this could be true, it is too early to make such claims at this stage. Research still needs to be done into the chemical processing installation, perhaps the material to be used for holding the liquid fluoride mixture, possibly the costs for building the reactors itself, and updated safety, licensing and environmental standards. If solutions to these issues lead to a complex the design the reactor might not be cost-effective. It is believed a relatively simple design will be possible, but it is premature to say for sure.

A number of 1 billion dollars has been mentioned as the amount still needed for research, but this is probably a very rough number, and it is not uncommon for estimates to turn out higher in practice.

One issue still left without a satisfactory answer is that of the concrete dome to protect the reactor. Some say the LFTR will not require this to be constructed which will lead to dramatic cost savings, while others think it might still be necessary, and workarounds like digging the reactor in will bring other costs with them.

Non-proliferation\(^\text{19}\)

With regards to proliferation, the truth lies in the middle. Thorium is not completely harmless when it comes to proliferation, but it has some advantages compared to uranium reactors. Although thorium can be used for a nuclear weapon it is not very practical and parties capable of using thorium are probably also capable of using uranium. Material being stolen from the reactor by ill-willing third parties for weapons use is unlikely however. Claims that thorium is completely proliferation resistant therefore are exaggerated. It has advantages in terms of proliferation resistance compared to uranium, but is not a shield against it.

Medical\(^\text{20}\)

The thorium fuel-cycle is said to produce certain isotopes that have valuable medical applications. This only comes from one source and needs further backing. Another question is whether the nuclear power plant is the only way of producing these isotopes, or if other paths are also open.

History\(^\text{21}\)

The reason thorium is not being used as a nuclear fuel today does not have to do with whether thorium is a better material for use as a nuclear fuel than uranium, but is due to historical reasons: in the early days of nuclear power development, choices had to be made as to which combination of fuel- and plant-type to pursue further, and  

\[^{16}\text{See: 5.2. Safer & 7.9: Competing reactor designs}\]  
\[^{17}\text{See: 5.3. More}\]  
\[^{18}\text{See: 5.4. Cheaper & 7.7. Cost effectiveness}\]  
\[^{19}\text{See: 5.5. Decreased proliferation danger & 7.8. Proliferation}\]  
\[^{20}\text{See: 5.6. Medical}\]  
\[^{21}\text{See: 6. History}\]
uranium was chosen because it had the properties desired from a nuclear fuel at that time, and it did the job. Since then, all of the research, funding, and other assets have been invested in uranium, creating a huge developmental gap that thorium has to catch up with.

9.1.2. Research question 2: Stakeholders

The development of the LFTR has many different stakeholders. In general they can potentially benefit from its cleaner waste profile, safer design, greater resource abundance, possibly cheaper electricity, improved proliferation resistance, and medical applications of its isotopes, and suffer from the fact that it still produces nuclear waste, be it a fraction of what is currently produced.

For the LFTR to be developed, governments probably need to step in by funding research. Such large amounts of funding (>1BLN) and time (15-20yrs) are needed that businesses are usually not willing to take the risk or invest those amounts of resources. Currently governments are not eager to invest either, because they usually do not have the long term vision required and are unwilling to invest in this type technology for similar reasons as businesses.

In the Netherlands energy policy is made at the “Table for Industry, largescale energyproduction and ETS”, a consultative body for representatives of umbrella organisations that have a say in energy matters, from energy producers, to lobby groups. To get the development of the LFTR considered therefore, the organisations represented there are the ones that need to be influenced.

Current Dutch policy on nuclear power has been described in a letter from the Minister of Economic affairs, M. Verhagen, to the House of Representatives. It states that although private sector parties are free to propose initiatives for building new reactors, these have to adhere to certain preconditions, the first one if which is that the nuclear power plant design has to be based on the newest technology, excluding those that are still in the developmental, or experimental phase, such as the LFTR.

For the LFTR to be developed in the Netherlands, current policy would have to change which could be achieved through lobbying, but starts with simply informing: during interviews with several of the stakeholder groups considered to be most important it became apparent that many organisations, including those working with energy, are not aware of the LFTR’s existence and/or its theoretical benefits. They are aware of thorium sometimes but seem to rely on incomplete or outdated information. Interestingly some lobby organisations do seem open to innovation in nuclear power.

The Netherlands has been used as an example of how this kind of decision making works, but a more realistic prospect might be a broader, transnational view. A European collaboration would be the obvious solution but this is hampered by member-states who are strongly opposed to any fission-based nuclear technology. Perhaps countries and other parties in favour of developing the LFTR should seek each other out and establish a joint venture based on whoever is willing to invest rather than existing partnerships. It seems that in this case, democratic decision making is making it very hard to invest in a technology like the LFTR.

The only country that is currently developing a Molten Salt Reactor is China. They have the resources to undertake large projects like this one and do not have to take other member states’ opinion into account.
9.1.3. Discussion

All in all, many of the LFTR’s supposed benefits appear to be real. The important aspects of reduced waste profile and reactor safety, as well as resource abundance and medical applications have not been found to be misrepresentations or strong exaggerations. The non-proliferation benefit does seem to be exaggerated by some: although the LFTR has benefits compared to the LWR in terms of proliferation-resistance, a world with only LFTRs would not necessarily mean a world without nuclear weapons. The cost benefit also seems premature, but could be accurate: although the LFTR might well turn out to produce cheaper electricity than LWR’s and possible even coal, we are at too early a stage to say for certain. Truly spectacular are designs that run on nuclear waste, if these can indeed be built it would mean a possible solution to the nuclear waste problem.

It looks like here is a new source of energy with great potential. Its possibilities deserve to at least be investigated to further lift the veil on their feasibility. The main reason its development currently isn’t pursued by most businesses and governments is because of the large investments in terms of time and resources involved, coupled with with the unknowns that still have to be researched. With that, it becomes a catch-22 situation: more research is needed to justify investments, while investments are needed for more research.

The development of this technology could have dramatic consequences for renewable energy business models, and with that, to international business and the IBS-lectoraat. If the general public perceives it at “sufficiently sustainable”, renewable energy faces competition from an energy source without the disadvantages of fossil fuel, the reliability and capacity of nuclear power, and greatly reduced “nuclear” disadvantages. Considering that the reactor is currently being developed in China, this is something to be aware of and anticipate on.

Finally, this is speculation but perhaps governments & businesses are not willing to invest the time and money in developing, testing, and getting the technology certified, because they are waiting for others to do the heavy lifting. It could be that once the initial hurdles have been taken and commercial LFTR’s are being built, the technology can be copied within a matter of years, making it strategically wiser not to invest directly but to wait for the technology to be developed by others. The technology is quite old, freely accessible, and many countries have done research into it which makes it seem not very strongly protected by patents. On the other hand, a company like Trans-atomic Power can apparently take old technology, slightly adjust it, patent the adjustment and expect to do well by it. This has to do with how well technology can be legally protected, which is beyond the scope of the current research.

9.2. Recommendations

Based on the above, it is recommended that the Hanze University continues research into the LFTR, and related technology. Areas that could be further explored in future theses include:

**LFTR costs.** Conflicting claims are being made about what LFTR’s will eventually cost. This is a key aspect because it is this uncertainty that plays an important role in governments’, and businesses’ decision whether to invest in developing the technology or not. Reliable estimates backed by convincing reasons would be a valuable addition to LFTR research. Perhaps one exists already but it did not turn up during the course of this research, and if not this is an area that could be further explored in future theses. A major factor seems to be whether a concrete dome needs to be constructed or not, and what alternatives would cost, which is something that should be discussed with experts on plant construction.
Further testing of theory. To limit the scope of this research, 2 experts have been asked for their opinions in this matter. It is advised to gather more expert opinions and compare them. The same goes for the rest of the theory, much of it came from multiple sources by reputable authors, but further examination is encouraged.

Reliable peer-reviewed information about the LFTR is not abundant. Because of this, it seemed like the same authors and articles kept coming up in other articles and reference lists. This raises the question whether there is enough impartial primary research or that authors are basing their work on a very limited pool of information, which might contain overstatements that are continuously repeated. Deeper research into the sources that exist on the LFTR to map where information originates, followed by further expert scrutiny is advised.

An area that might be of especial interest to the IBS-lectoraat is that of the stakeholders. International business students wanting to explore this subject further might be better equipped for understanding and influencing stakeholder groups and decision making processes than developing the technological aspects of the LFTR, although they might be able to contribute to the management and strategy of the technological process. It seems that many vital stakeholders are currently unaware of the LFTR’s existence and/or its benefits, so much ground can be won simply by informing. An example is Stichting Laka, a foundation documenting information about nuclear power. Other anti-nuclear lobby-groups base their viewpoints on Laka’s information but it appears that Laka’s viewpoint on thorium is based on different reactor types than the LFTR. Investigating whether this is really the case would be very valuable but was not followed-up on in this research as a way of limiting scope.

Investigate the potential of competing reactor designs. Several designs have been identified, some of which show great potential. A deeper investigation into the relative benefits of these, and possibly other designs compared to the LFTR/MSR might yield new insights into the LFTR’s relative value.

The role of the uranium industry. The uranium industry might be a very important stakeholder. Switching to an alternative fuel source could be disastrous to them, which might cause them to oppose the LFTR. The uranium industry currently equals the nuclear industry however so they could also be instrumental in developing the technology. Further investigation of this stakeholder is advised.

Protection of intellectual property. An interesting question to explore is if China were to develop this technology, would they be able to keep it to themselves? The basic technology is freely available online and scientists are capable of making educated guesses as to what the missing components will look like. Would China be able to successfully patent these, or could other countries copy what they did relatively easily after they have done most of the heavy lifting? If so, this might be an alternative explanation for why countries don’t seem eager to pursue the technology themselves, and it would be quite the revelation as it is not mentioned as a reason anywhere.

Another issue not directly related to the LFTR came up during the course of this research: in general it would be of considerable value if research conducted on (Hanze) theses that yields important information would be followed up on, either by future research or otherwise. A system could be developed where theses with future follow-up potential could be nominated by its supervisors, to ensure many hours of work and possibly important information are not lost, if such a system does not exist already of course.
Recommendation to anti-nuclear lobby groups

It is recommended to keep an open mind to these kinds of new technologies. A world where all energy comes from true renewables would be ideal but the question is whether this is a realistic prospect. Global energy demand will see a large increase, particularly in developing parts of the world, and investments in nuclear power are likely to be continued to be made. If this is the reality, it might be strategic to demand that any funding going towards nuclear power is invested in developing cleaner, safer technologies, instead of building reactors based on the same dated designs. Especially technology like the Waste Annihilating Molten Salt Reactor, that has the potential to solve the current long-lived nuclear waste problem, should have a place in environmentally driven agenda’s.

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23 Transcends research question 3 but was deemed important to include.
10 Evaluation of- and reflection on the project process

The project process went satisfactory. There were difficulties that had to be overcome but these were all dealt with and none led to serious problems. The most important ones were the research design and access to sources.

The research design was challenging because the research was non-traditional and therefore a framework had to be developed that was challenging and interesting while still adhering to International Business School Graduation Project standards. At the outset of the project there was also uncertainty as to whether the subject matter would not turn out overly challenging, but this was countered with an immediate thorough immersing in the theory after which it rapidly proved feasible.

Reliable sources on the Liquid Fluoride Thorium Reactor are not abundant so it was very important that the ones that exist would be identified and consent to cooperate. Preparations were made to increase the chances of this coming to pass and interviews were secured.

The planning was always stuck to and most of the work and all of the raw data was ready by the time the draft report was due, leaving enough time for finalising the rest of the project. This included work on layout design and the development of an “info graphic” on the subject, as requested by another researcher.
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Appendices

A Interview summaries

A1. EXPERTS

Interview Jan Leen Kloosterman

Je moet de uraniumcycus beheersen om met thorium aan de slag te kunnen. Uranium is eigenlijk heel goedkoop, dus thorium energie moet wel heel goedkoop worden wil het kunnen concurreren.

You have to master the uranium cycle to be able to work with thorium. Uranium is very cheap really, so thorium energy has to become very cheap if it is to be competitive.

Er moet nog heel wat onderzoek naar de LFTR gebeuren, dus bedrijven zijn niet happig op daarin investeren als de uraniumcyclus ook gewoon voorhanden is.

The LFTR still requires a lot of research, so companies are not eager to invest when the uranium cycle is still available.

De LFTR is de optimate reactor om thorium in te gebruiken, mede omdat de LFTR zelf de kettingreactie in stand kan houden.

The LFTR is the optimal reactor to use thorium in, in part because the LFTR can sustain the chain reaction.

De demonstratie LFTR reactor in Oak Ridge heeft aangetoond dat je thorium toe kan passen in een reactor, dat je thorium om kan zetten in splijtbaar uranium, dat je uranium kan kweken (meer produceren dan je gebruikt), wat niet gedemonstreerd is zijn de processen om het zout/uranium continu te zuiveren. Dit omdat zuivering batch-gewijs gebeurde in een aparte fabriek, en dit moet eigenlijk continu in een fabriek die parallel draait met de reactor gebeuren. Dit is het grootste obstakel op het moment.

The demonstration reactor in Oak Ridge demonstrated that you can use thorium in a reactor, that you can transform thorium into fissionable uranium, that you can can breed (produce more than you use), what has not been demonstrated are the processes to continually cleanse the salt/uranium. Cleansing happened by the batch in a separate factory, but this should really happen continuously in a factory running parallel to the reactor. This is currently the biggest obstacle.

Verder zijn materiaalsoorten een mogelijk obstakel: alhoewel de reactor in Oak Ridge materialen heeft gebruikt die je nu ook zou kunnen gebruiken (Hastelloy-N), maar omdat de regels strenger zijn geworden moet het staal waarschijnlijk opnieuw getest worden, en dat duurt erg lang.

Apart from that, materials are a possible obstacle: although the reactor in Oak Ridge used materials that you could use again, (Hastelloy-N) the rules have become stricter and the steel would have to be tested again, which takes a long time.
Al met al zal het onderzoek nog zeker 15 jaar in beslag nemen.

All things considered the research will take at least 15 years.

Het is nu nog moeilijk te zeggen of de praktijk zo uit zal pakken als de theorie. J.K. vermoedt van wel want het zijn niet heel moeilijk processen, maar je kan het niet met zekerheid zeggen nog.

It is hard to say at this time whether practice will turn out like the theory predicts. J.K. suspects it will because the processes involved are not very complicated, but you cannot say for certain.

Verder moet de veiligheid van de reactor ook nog verder onderzocht worden, alhoewel het er naar uitziet dat je de reactor wel inherent veilig kan maken.

Apart from that the reactor safety needs to be further researched, although it looks like you can make the reactor inherently safe.

Verder zijn investeringen een struikelblok: de politiek en bedrijven hebben vaak een te korte termijn visie, en er is weinig geld door de crisis.

Investments are another obstacle: politicians and companies often have too short a vision, and there is little funding due to the crisis.

In China lijkt men wel een lange termijnvisie te hebben, daar werken ze nu aan een demonstratierector.

In China they do seem to have a long-term vision, they are building a demonstration reactor.

J.K. heeft hoge verwachtingen van de prestaties van de LFTR in de praktijk.

J.K. has high expectation of the LFTR’s performance in practice.

Wanneer men spreekt van “veilig” radioactief afval heeft men het over afval dat weer de radiotoxiciteit heeft van toen het als uranium uit de grond kwam.

When we speak of “safe” radioactive waste, we are talking about waste that has the same levels of radiation as when it came out of the ground.

De hoge temperatuurreactor deelt het voordeel van inherente reactorveiligheid, maar niet het afval voordeel van de LFTR.

The high temperature reactor has to advantage of inherent reactor safety, but not the waste advantage of the LFTR.

Splijtingsproducten kunnen uit de gesmolten zout mix worden gehaald dmv “helium bubbling”, heliumbelletjes door de zout vloeistof laten bubbelen die korreltjes vaste splijtingsproducten eruit zuiveren.

Fission products can be removed from the salt mixture by “helium bubbling”, having helium bubbles bubble through the liquid to purify bits of solid fissionproducts out.

China zet in op (vrijwel) alle energievormen, ze hebben het geld ervoor.
China invests in (almost) all forms of energy, they have the money for it.

De Europese unie zou eigenlijk achter thorium/LFTR aan moeten gaan maar doet dit tot op heden niet. Er is wel aandacht voor kernfusie omdat dit politiek makkelijker te verkopen is.

The European Union should really be pursuing the LFTR but has not until now. Nuclear fusion is being pursued, because this is easier to defend politically.

Bepaalde groepen op internet geven een te rooskleurig beeld van wat de LFTR allemaal kan, met name wat mbt de termijn waarop het ontwikkeld kan worden. Soms lees je binnen 5 jaar, en dat klopt waarschijnlijk niet. 15 jaar voor een demonstratie reactor, en 20 voor commerciële toepassing.

Certain groups on the internet are giving too positive an image of what the LFTR can do, especially with regard to the time it will take to develop the LFTR. Sometimes you read within 5 years which is probably not true. 15 years for a demonstration reactor, and 20 for commercial deployment.

Er zijn ook groepen die de LFTR nu al afserveren omdat er onoverkomelijke problemen mee zouden zijn, dat is ook niet juist, het is een kwestie van tijd en geld.

There are also those who already dismiss the LFTR because there would be insurmountable problems with it, but this is not correct either, it’s a matter of time and money.

15 jaar is onder gunstige omstandigheden wbt tijd en geld, en meer geld en mensen erop zetten zal dit niet veel versnellen omdat bepaalde processen nou eenmaal veel tijd kosten.

15 years is under the best of circumstances in terms of time and money. Putting more money and manpower on it will not speed this up much because certain processes simply take a lot of time.

Alhoewel er misschien problemen in bijvoorbeeld de zoutzuiverings processen kunnen opduiken, kunnen deze waarschijnlijk omzeild worden door alternatieve methodes te gebruiken, showstoppers worden niet verwacht.

Although problems in (for example) the salt purifying processes, these can probably be circumvented by using alternative methods, showstoppers are not expected.

Een grote vraag is of de LFTR economisch redabel gemaakt kan worden, als de complexiteit uiteindelijk mee blijkt te vallen is de kans dat dat lukt groot.

A big question is whether the LFTR can be made economically viable, if complexity turns out to be low chances that this will be the case are good.

Materiaal voor de buizen zal wellicht meevallen omdat LFTR buizen dunner kunnen zijn dan de buizen in reactors die onder druk werken.

Material costs for the tubing will possibly turn out to be relatively low because tubes can be made thinner than tubes in reactors that are under pressure.

De hoogste kosten van de LFTR zitten waarschijnlijk in het beton. Een koepel is waarschijnlijk toch nodig om tegen inslag van buitenaf te beschermen. Verder is gaten graven om een
koepel te vermijden waarschijnlijk ook duur, oa door betonnen drukwanden.

The highest costs for the LFTR are probably in its concrete. A dome is probably necessary after all to protect against outside impact. Apart from that, digging holes to take away the need for a dome is probably expensive too, because of concrete pressure walls for example.

Dat er niet genoeg U-233 voorhanden zou zijn om een breed thorium programma op te starten is geen belemmering, dit kan worden vervangen door uranium-235 of plutonium-239.

There not being enough U-233 to start a large scale thorium programma is no problem, this can be replaced by uranium-235 or plutonium-239.

Een “compact heat exchanger” is waarschijnlijk ook niet overdreven duur.

A “compact heat exchanger” is probably not too expensive.

“Thorium” kernafval van de LFTR kan op dezelfde wijze opgeslagen als uraniumafval.

Thorium nuclear waste can be stored in the same way as uranium nuclear waste.

Helium bubbling wordt momenteel nog onderzocht dus het is nog niet bekend hoe goed dit werkt, of het als oplossing volstaat.

Helium bubbling is currently being researched so it is not known if this suffices as a solution, and how well it works.

Er kunnen wel kernwapens gemaakt worden met materiaal afkomstig uit een de thoriumcyclus, maar de uraniumcyclus is makkelijker. Je kan de LFTR wel zo inrichten dat het mogelijk wapenmateriaal onbruikbaar maakt, maar dat moet de eigenaar van de reactor dan wel expres doen dus. Dus als een schurkenstaat dat zou willen, kan materiaal uit de LFTR gebruikt worden, maar het kan wel beschermd worden tegen diefstal van materiaal, bijvoorbeeld door het expres onbruikbaar te maken.

Nuclear weapons can be produced with material from the thoriumcycle, but the uranium cycle is better suited for this. You can build the LFTR in such a way that it makes possible weapons material unsuitable for use in nuclear weapons, but this would have to be done by whoever is in charge of the reactors. So if a rogue state would want to, material from the LFTR could be used, but it can be protected against theft, by making it unsuitable for use.

Snelspectrumreactoren halen dan wel 50 keer meer energie uit uranium, maar rendabel zijn ze niet.

Fast neutron reactors might be able to get 50 times more energy from uranium, but they’re not cost-efficient.

Het is te vroeg om te zeggen dat de LFTR goedkoper zal uitpakken dan andere reactortypes, er is eerst meer onderzoek nodig om daar duidelijk over te krijgen.

It is too early to say that the LFTR will turn out cheaper than other reactortypes, more research is needed to make that clear.
Interview “Nuclear chemistry expert”

Er is een schema op papier ontworpen voor de MSBR, dat is echter nooit echt getest en of alle stappen ook echt functioneren moet nog onderzocht worden.

A plan was developed on paper for the MSBR, this has never been tested however and if all the steps function as they should still needs to be researched.

“Nuclear energy expert” denkt dat het zeker op te lossen is, maar hoe moeilijk dat zal zijn is nog niet te overzien. Het is niet onoverkomelijk, maar de vraag is hoe duur de oplossing zal zijn. Dat hangt o.a. van de complexiteit van het ontwerp af. Er zijn tegenwoordig nieuwe ontwerpen die het wellicht onnodig maken hele grote volumes te zuiveren.

“Nuclear energy expert” thinks this can definitely be solved, but how difficult this is, is hard to say. It is not insurmountable but the question is how expensive it will turn out to be.

Het zuiveren van zout moet gebeuren om splijtingsproducten eruit te halen, gedeeltelijk zijn dat stoffen die storen (zoals xenon) en het is het uraan, dat je elders wilt gebruiken.

The salt has to be purified to remove fission-products, part of these are products that disrupt (like xenon), and it is uranium that you want to use elsewhere.

Het is nog niet te zeggen hoe duur de zuiveringsprocessen zijn. Er worden wel vergelijkbare processen in bijvoorbeeld de aluminium industrie gebruikt, maar dat gebeurt onder heel andere omstandigheden.

Right now we cannot say how expensive those purification processes will be. Similar processes are used in the aluminium industry for example, but this happens under very different circumstances.

Er moet een aparte fabriek met een ingewikkeld chemisch proces gebouwd worden. Die zal zeker een paar honderd miljoen euro kosten.

A seperate factory with a complicated chemical process has to be constucted. That will cost at least a few hundred million euros.

Andere reactor ontwerpen kosten al snel een aantal miljard om te bouwen, zoals de EPR in Finland.

Other reactor designs often cost a few billion to build, the EPR in Finland for example.

Misschien is het ook mogelijk een “eiland” van een aantal reactors te bouwen die dan 1 chemische fabriek delen. Ook zijn er concepten van Amerikaanse bedrijfjes die de kern van een kleine reactor eens in de zoveel jaar naar de zuiveringsinstallatie willen vervoeren om het daar te zuiveren.

It might also be possible to construct an “island” out of a couple of reactors that then share 1 chemische factory. There are also concept from American companies that want to move the core from a small reactor to the purification plant once every few years.

Er zijn tegenwoordig waarschijnlijk betere materialen dan Hastelloy-N te vinden voor gebruik
in de LFTR. De prijs van deze metalen zal geen grote invloed hebben op de kosten voor de bouw van een LFTR.

There are probably better materials than Hastelloy-N to be found for use in the LFTR nowadays. The price of these metals will not have a big influence on LFTR construction cost.

Beryllium is kankerverwekkend en daarom is het wellicht wenselijk daar een vervangende stof voor te vinden. Het kan wel gebruikt worden maar productie en gebruik van de stof moet aan hoge veiligheidseisen voldoen.

Beryllium is a carcinogen and because of that it might be wise to find a different chemical to replace it. It can be used, but production of such a substance has to adhere to strict safety standards.
A2. Stakeholders

Stakeholders interviewed were:

CDA

World Service on Energy

Duurzame Energie Koepel

Natuur & Milieu

Henk Berendsen

Milieudefensie

The table below summarizes the stance on- and familiarity with nuclear power and the LFTR of 5 stakeholders deemed most important. It includes the Ministry of Economic Affairs although they were not interviewed but outlined their stance by e-mail. The CDA and the Ministry of Economic affairs are most open to nuclear power, but the latter views the LFTR as too far from implementation. These 2 are also the ones with most knowledge of the LFTR, all others had a limited knowledge of the technology. What was surprising was that DE Koepel and WISE were open to these types of innovation, providing an opportunity for informing and possibly persuading.

Stakeholder interviews overview table

<table>
<thead>
<tr>
<th>Organisation</th>
<th>Stance on nuclear power</th>
<th>Familiar with LFTR</th>
<th>Stance on LFTR</th>
<th>Stakeholders mentioned</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDA</td>
<td>Nuclear power deserves a spot in total energy production</td>
<td>Yes</td>
<td>Positive, but no official stance</td>
<td>Civil servants, table for largescale energy production, Mr Berendsen, European Union, VVD</td>
</tr>
<tr>
<td>WISE</td>
<td>Against</td>
<td>Limited</td>
<td>Open to new technologies</td>
<td>Uranium lobby</td>
</tr>
<tr>
<td>DE Koepel</td>
<td>Against, pro-renewables</td>
<td>Some</td>
<td>Open to innovation but prefers renewables</td>
<td>Nature &amp; environment, future generations</td>
</tr>
<tr>
<td>Natuur &amp; Milieu</td>
<td>Against, pro-renewables</td>
<td>No</td>
<td>Too far from implementation</td>
<td>Uranium lobby, government</td>
</tr>
<tr>
<td>Ministry of economic affairs</td>
<td>Open to private sector proposals</td>
<td>Yes</td>
<td>Too far from implementation</td>
<td>Private sector, Jan Leen Kloosterman</td>
</tr>
</tbody>
</table>

Interview Marieke van der Werf (CDA) - former member of the Dutch house of representatives for the CDA (Christen Democratisch Appèl) and spokeswoman for...
**energy matters.**

Er is geen beleid op het gebied van thorium, alleen beleid over kernenergie. Het standpunt van CDA is dat kernenergie een plek verdient in de totale energie-mix vanwege het CO2 voordeel en de betrouwbaarheid van levering en de betaalbaarheid.

The CDA has no policy on thorium, only policy on nuclear energy. The CDA believes that nuclear energy deserves a place in the total energy-mix because of the CO2 advantage and the reliability of supply and affordability.

Het CDA heeft net als een paar andere partijen, geen standpunt over thorium geformuleerd.

The CDA has, like a number of other parties, no official policy about thorium.

Veel mensen in de partij weten niet van het bestaan van (kernenergie op basis van) thorium af.

Many people in the party don’t know about the existence of thorium-based nuclear power.

Betrouwbaar onderzoek over thorium is waardevol om mensen erover te informeren. Het is vooral ook belangrijk dat ambtenaren op het ministerie ervan weten want die gaan uiteindelijk over beleid.

Reliable research about thorium is valuable to inform people about it. It is especially important that civil servants in the ministries know about it because they decide about policy in the end.

M.W. denkt dat andere partijen ook geen standpunt hebben door onbekendheid met het onderwerp, want ze heeft hen er nooit over gehoord.

M.W. thinks other parties don’t have an official opinion about thorium because they are unfamiliar with the subject, and have never heard about it.

Er is een “tafel” grootschalige energieopwekking bij de Sociaal Economische Raad waar vertegenwoordigers van koepelorganisaties van energiebedrijven, lobby-groepen, en anderen die iets te zeggen hebben over energiebeleid in Nederland onderhandelen over energie. Degene die daar aan tafel zitten zijn daarmee belangrijke stakeholders in Nederlands energiebeleid.Aan deze tafel valt het woord thorium niet.

A “Table for Largescale Energy production” at the “Social Economic Counsel” exists where representatives of umbrella organisations for energy companies, lobby-groups, and others who have a say in Dutch energy policy negotiate energy policy. Those who have a place at this “table” are therewith important stakeholders in Dutch energy policy. On this table the word “thorium” is not uttered.

Meneer Berendsen is ook enthousiast over thorium en benaderde mevrouw van der Werf met de vraag wat het CDA met thorium deed en dat was nog niks, want het onderwerp was nieuw.

Mr. Berendsen is a thorium enthusiast ho approached Ms. Vd Werf to inquire about what the CDA was doing in this matter, which was nothing, because the subject was very new.
Kabinetten kijken niet ver genoeg vooruit om in dit soort technologie te investeren, ze willen scoren op korte termijn en geld is schaars.

Cabinets do not look far enough ahead to invest in this kind of technology, they want to score in the short term and money is scarce.

Kapitaal voor deze technologie aantrekken is erg moeilijk door onzekerheid over het rendement. Een Europese coalitie zou misschien een optie zijn.

Attracting capital for this technology is very difficult because of uncertainty about the cost-efficiency. A European coalition might be an option.

De VVD is de enige partij die positievere tegenover kernenergie staat, Renee Leegte is woordvoerder energie.

The VVD is the only party that is positive about nuclear power. Renee Leegte is their spokesman for energy matters.

Interview World Information Service on Energy - International network organisation that is strongly opposed to nuclear power.

Wise heeft beperkte kennis van de LFTR. Raden Laka aan.

Wise has a limited knowledge of the LFTR. They recommend Laka.

WISE gelooft niet in de toekomst van kernenergie, welke technologie dan ook. Thorium wordt al decennia genoemd als een doorbraak, maar die doorbraak blijft uit.

WISE does not believe in the future of nuclear power, any technology whatsoever. Thorium has been mentioned as a breakthrough for decades, but that breakthrough never materializes.

Zelfs al zou het mogelijk zijn, dan moet je als wereld de hele infrastructuur omgooien, dus dat maakt het onwaarschijnlijk.

Even if it would be possible, you would have to change the entire worldwide infrastructure, which makes it unlikely.

Al het geld moet naar renewables. Er moet een keuze worden gemaakt waar geld naartoe gaat.

All funding should go to renewables. Choices have to be made where to allocate money to.

De thorium cyclus heeft ook voordelen, maar er is wel nog wat afval & gevaar.

The thorium cycle also has advantages, but there still is some danger and waste.

WISE is niet tegen nieuw onderzoek.

WISE is not opposed to new research

Het klimaatprobleem heeft renewables nodig. Thorium technologie komt te laat.
The climate problem needs renewables. Thorium technology comes too late.

Innovatie & investeringen in renewables gaan met sprongen omhoog. Percentage dat renewables bijdragen aan mondiale energieproductie is nog laag, maar als leercurves nog meer vernsneld kunnen worden kunnen renewables op tijd komen.

Innovation and investments in renewables are rapidly increasing. Mondial renewable energy contribution is still low, but if the learning processes can be further accelerated, renewables can still be on time.

Het gebeurd wel vaker dat er een nieuw reactortype wordt voorgesteld, en dan ontstaat er een strijd tussen de bestaande “uranium sector” en de nieuwe technologie.

It happens more often that a new reactor type is proposed, and this unleashes a battle between the existing “uranium sector”, and the new technology.

Overstappen op thorium zou het einde van de kernindustrie kunnen zijn. Als het niet werkt is het een afgang voor de kernindustrie, en als het wel werkt heb je en schonere, veiligere, goedkopere technologie.

Switching to thorium could mean the end of the nuclear industry. Is it doesn’t work it is a blow to the nuclear industry, and if it does work you have cleaner, safer, cheaper technology.

Nieuwe technologie zal niet geaccepteerd worden door de uranium sector.

New technology will not be accepted by the uranium sector.

Het is misschien niet aan een milieuorganisatie zoals WISE om te pleiten voor iets als thorium, al het geld moet naar renewables, maar het kan strategisch slim zijn om te zeggen: als er al geld naar kernenergie gaat, dan op zijn minst naar iets beters zoals thorium.

It might not be a environmental organisation like WISE’s place to argue for something like thorium, all funding should go to renewables, but it could be strategically smart to say: If money is going to go to nuclear energy, then at least invest it into something better like thorium.

Onderzoek opsturen. WISE gooit niet bij voorbaat deuren dicht als ze er niet over geïnformeerd zijn. Naar: info@wise.nl.

Send research. WISE doesnt rule out anything when they are not yet properly informed.


This conversation can be used in the research. Spoken with: Peer de Rijk.

Er zijn nog publicaties van WISE die kunnen worden opgestuurd.

There are publications that WISE can send

Interview Duurzame Energie Koepel - organisation that represents the interests of the Dutch sustainable energy sector.
Ms. Van Eijkelenburg knows something about the technology, for example that smaller versions of this type of reactor can be built.

CO2 emission and ETS are themes that are negotiated at the Table for Largescale Energy Production. Both short- and long term goals are discussed.

DE Koepel has written in her statutes that they do not want to leave any waste behind for future generations. That is the starting point for all of DE Koepel’s activities. Sustainable means renewable, so that you have an infinite source, don’t inflict irreparable damage to man, nature and environment, and that you sustain the biodiversity. They look at the whole system, so from CSR they look at all aspects of sustainability. They represent the interests of truly renewable forms of energy. Her association with other subjects like shale gas, CO2 storage at sea, and coal plants is that it is discussed.

When you compare regular nuclear power to the LFTR, the LFTR sounds better, but every kind of nuclear energy leaves harmful waste behind and that is unnecessary. DE Koepel is not opposed to new technology, but the entire cost of new technologies, including costs for potential disasters or accidents caused by waste have to be taken into account. Is it is still cheaper than other energy sources, it can be considered.

DE Koepel ziet liever investeringen in de eindoplossing, nml echt duurzame energie zoals wind en zon, in plaats van alles in te zetten op een technologie die risico’s verminderd maar niet helemaal wegneemt.

DE Koepel’s would rather see investments in a true solution, meaning real sustainable energy like wind and solar, instead of putting all your resources on a technology that reduces risk but doesn’t remove it.
Renewable energy could have been sufficient as an energy source, but enough has not been invested yet.

Als dit aan de orde komt wilt DE Koepel dit uitgebreid intern bespreken om te kijken wat hun officiële standpunt is in deze kwestie.

If this technology becomes relevant, DE Koepel wants to discuss this in depth to decide what their official stance on this subject is.

Vooral integraal alle kosten en effecten meerekenen in dit soort kwesties is van groot belang.

Especially calculating all costs associated with issues like this is extremely important.

*Interview Natuur & Milieu - Organisation promoting sustainability.*

Geen expliciet standpunt hierover. Natuur & Milieu vindt: waarom zouden we dit doen als we ook met duurzame energy aan onze energievraag kunnen gaan voldoen? Duurzame energie wordt steeds goedkoper, en met genoeg inzet moet dit kunnen.

They do not have an explicit viewpoint on LFTR technology. They wonder why one would invest in this technology when you can also use renewable energy to meet energy demand. RE is getting increasingly cheaper, and with sufficient input it should be possible.

Hoe lang duurt dit? Moet er overheids geld naartoe? Hoe duur is de electriciteit uiteindelijk? Normale kernenergie berekent vaak niet alle kosten die van toepassing zijn door.

How long will developing this technology take? Does it need government funding? How expensive is electricity going to be? Conventional nuclear power often does not calculate all relevant costs into the price of electricity.

Er zijn genoeg studies waaruit geconcludeerd wordt dat duurzame energie kan volstaan als energiebron, dat zou dan 90-95% renewable en een stukjes “fossiele” energie zijn. Technische is het mogelijk.

There are plenty of studies that conclude that renewable energy can suffice as an energy source, that would be 90-95% renewables and a bit of “fossil” energy. This is technically feasible.

Een thorium lobby is iets heel anders dan een uranium lobby. De bestaande uranium lobby zal niet blij zijn met een thorium lobby.

A thorium lobby is an entirely different thing than the uranium lobby. The existing lobby will not be happy about a thorium lobby.

Natuur & Milieu’s standpunt is dat duurzame energie bronnen zullen volstaan, en kernenergie niet nodig is.

Natuur & Milieu’s stance is that sustainable energy suffices, and nuclear power is unnecessary.
There are many technologies with great potential that are still far from implementation. Natuur & Milieu doesn’t deal with technologies that are so far from implementation. Algae breeding for example is such a subject that should be further researched.

De belangrijkste stakeholder in deze kwestie is waarschijnlijk de overheid, bedrijven zullen hier wel geen geld in willen steken.

The most important stakeholder is probably the government, companies will not want to invest in this.

Nuclear fusion is another example, it is so uncertain and far away that companies will not invest, so you will need government funding.

Later mail sturen met wie dit onderzoek allemaal te zien krijgen.

Send e-mail with who will be reading this research.

Interview Henk Berendsen – Private thorium/LFTR enthusiast

Mr. Berendsen is nuclear physicist, graduated in Utrecht, in the area of applied physics. After that he worked for Shell in oildrilling, has been a teacher and worked in IT.

His interest in the LFTR was sparked after reading 2 articles, 1 in “intermediar” 22, from June 3rd 2011 “Green nuclear power: totally 21st century” and “Green nuclear energy is possible” in the “Twentsche Courant Tubantia” from December 11th 2010.

Naar aanleiding daarvan vorig jaar contact gezocht met de politiek, Marieke van der Werf van het CDA was enige geïnteresseerd. Zij heeft toen een studie toegestuurd over thorium.

Because of this he contacted politicians about this subject last year. Marieke van der Werf of the CDA was the only one who was interested, she then also sent a report about thorium.
PVDA ook aangeschreven, Diederik Samsom want die is kernfysicus. Hieruit kwam naar voren dat er nog veel onderzoek moest gebeuren, niet op korte termijn bruikbaar is, en daarom niet zo interessant voor de politiek. Samsom was ook te druk.

**Also contacted the PVDA, Diederik Samsom because he is a nuclear physicist. From this he learned that much research still needs to be done, it will not be ready short term, and because of this it is not very interesting to politicians. Samsom was also too busy.**

Groenlinks heeft een grote voorkeur voor wind en zon. Voordelen ten spijt, ze hebben geen belangstelling.

**Groenlinks has a strong preference for wind and solar, regardless of the LFTR’s advantages, they are not interested.**

Je moet waarschijnlijk nog niet bij de politiek zijn, maar zelf een club mensen beginnen om hier onderzoek naar te verrichten en het onderwerp bekender maken. Lobbyen.

**It is probably too early to approach politicians, but better to start a group of people who conduct research into the subject and promote it. Lobbying.**

Er moet sprake zijn van grote politieke en technische wil om de LFTR te realiseren.

**Great political and technical will is necessary to make the LFTR a reality.**

Inherente veiligheid is grootste voordeel. Einde 2e wereldoorlog is er besloten uranium te gebruiken, omdat er plutonium nodig was voor kernwapens.

**The inherent safety is the biggest advantage. At the end of WWII it was decided to use uranium, because plutonium was needed for nuclear weapons.**

Bedrijven die met uranium werken zullen zich wellicht verzetten tegen een overstap op thorium.

**Companies working with uranium might resist against a switch to thorium.**

Een aantal landen zijn met thorium bezig, China voorop.

**Several countries are developing thorium, with China in the lead.**

Producten die vrijkomen bij de thoriumcyclus zijn heftig stralend, maar hebben daarom kortere halfwaardetijden.

**Products that are released in the thoriumcycle are very radioactive, but have shorter halflifes because of this.**

Politici hebben een te korte-termijn visie, nml 4 jaar. Daarom en omdat er geen geld is, is er geen steun vanuit deze hoek.

**Politicians have a short-term vision of 4 years. Because of this and because there is no money, there is no support from this direction.**

Atoomtechnologie is tegengehouden omdat er ongelukken zijn gebeurd. Mensen hebben het over kernwapens terwijl dat nauwelijks met atoom energie te maken heeft.
Nuclear technology has been stopped because of the accidents that happened. People talk about nuclear weapons while that does not have much to do with nuclear energy.

Stakeholders zijn de politiek, bedrijven als Shell misschien, Urenco, ministerie van EZ.

Stakeholders are politicians, companies like Shell, maybe Urenco, and the Ministry of Economic Affairs.

Marieke van der Werf hoorde voor het eerst over thorium van meneer Berendsen.

Marieke vd Werf first heard about thorium from Mr. Berendsen.

Angela Merkel schaft kernenergie af in Duitsland, dat is verrassend want zij is ook kernfysicus (net als Samsom).

Angela Merkel scapped nuclear energy in Germany. This is remarkable because she is a nuclear physicist as well. (like Diederik Samsom)

Politici nemen vaak geen risico’s, ze zijn kwetsbaar.

Politicians don’t take risks, they are vulnerable.

Als China deze technologie ontwikkelt en weet te patenteren, moeten wij hen straks betalen voor deze technologie. Wij krijgen dan een slechte concurrentie positie door dure energie.

If China develops this technology and manages to patent it, we will have to pay them for this technology. We will have a poor competitive position because of expensive energy.

Andere nieuwe (kern)energie technologieen moeten ook worden bekeken om thorium op waarde te schatten.

Other nuclear energy technologies also need to be reviewed to assess thorium on its merit.

*Interview Milieudefensie – Organisation representing environmental interests, focusing on the themes: International, traffic and sustainable food.*

Milieudefensie raadt aan met WISE contact op te nemen omdat zij zich specifiek bezig houden met kernenergie.

Milieudefensie advises to contact WISE because they focus specifically on nuclear energy

Milieudefensie’s standpunt is dat ze op kernenergie tegen zijn.

Milieudefensie’s stance is that they are against nuclear energy.

Kernenergie dat niet slecht is voor het milieu is een optie, maar de crux zit hem erin dat het “nauwelijks” slecht is.

Nuclear energy that is not bad for the environment is an option, but the crux is that
it is “almost” not bad for the environment

Voorstanders van kernenergie zeggen ook dat het nauwelijks slecht is.

Proponents of conventional nuclear power also argue that it is “almost” not bad for the environment.

Milieudefensie heeft op dit moment geen energiedeskundige in huis.

Milieudefensie does not have an expert on energy in their organisation at this moment.

A3. Interview questions

Interview questions Jan-Leen Kloosterman

Introduce myself

For starters, thank you very much for consenting to this interview, there are not many experts on thorium so I greatly appreciate your cooperation.

Can I record the interview?

Do you have any questions before we get started?

Can I use your name and answers in my thesis?

Shall I send you the written-out interview?

I will be making notes to make the interview run smoother, don’t pay too much attention to it.

I am conducting a research into the advantages and disadvantages of thorium-based nuclear power because thorium appears to have great advantages with regard to waste, reactor and weaponsafety, energy potential, and costs. If this is as good as it sounds it is an important development and competitor to existing energy sources, so the question that always presents itself regarding the LFTR is: if it truly has these advantages, why is more not being done to develop it?

2. What are the most important and/or –difficult hurdles that have to be taken on a technical level to reach a point where energy can be generated on a large scale using the LFTR in your opinion?

Is het crystal clear for you what still has to happen or are there factors involved about which little can be said with much certainty at this moment?

2. What are the most important and/or –difficult hurdles that have to be taken in other areas? Political or other interests?

Historical?
**Hard to switch to another system?**

3. What can you say about how the LFTR will perform in practice relative to what is expected of it? A test reactor has been in operating in the 1960’s, but did this demonstrate everything? (this reactor might have been different from what is required today)

**Will practice turn out like the theory?**

**What can you say about possible problems that only service in practice? How likely is this?**

4. What about different reactor types, the new generation reactors shares a number of the LFTR’s advantages, so how big are the LFTR’s advantages in comparison?

**Big enough to make serious investments?**

5. Who are the most important stakeholders in developing this technology according to you, in the Netherlands and internationally?

6. There are examples of documents where reasons are given why the LFTR would not work, and as many that disprove these. What can you say about this?

**Do you think the authors of these documents are wrong? If so, do you think they see a sincere problem or could there be other interests involved? Are there forces that a stake in the LFTR not being developed?**

**Technical questions**

7. The salt solution that is used in the LFTR is very aggressive/corrosive so the parts that hold this solution have to be very durable. A possibility is the Hastelloy-N allot, but this seems to be very expensive. What can you say about this aspect of the LFTR?

These parts also have to endure neutron radiation and very high temperatures, what can you say about this?

**How are these problems solved, is it sure that the solution suffices, and how does it influence the LFTR’s costs?**

8. For starting the thorium reaction, an amount of U-233 is required. Currently there isn’t sufficient U-233 available, can you say how enough U-233 for a large-scale program will be acquired and how long this will take?

9. Because of loss of delayed neutrons, the LFTR needs a “compact heat exchanger”, how expensive/complicated is something like this?

10. Although there is less waste, there is an amount of highly toxic waste, what can you say about storage of this waste?

**Might other methods be needed to handle thorium waste? If so, which investments in terms of time and money are needed to get these on a high enough level?**

11. A build-up of noble metals develops in the piping, is there a solution to deal with this?
12. What can you say about the removal/maintainance of spent graphite?

13. Does the LFTR have a reduced risk of nuclear weapons being built with material from the reactor? This is said but there are others who say it is possible. Uranium-233 is mentioned as an excellent candidate for nuclear weapons by Peter Baeten. What is your view on this?

14. In the article in “De Morgen” from the 23rd of January “Thorium, future nuclear miracle or eternal hype” in which you are mentioned as well, Peter Baten, director of the study center for advanced nuclear systems in Mol, Belgium, states that thorium’s advantages are greatly overestimated, a hype based on the Indian interest in the technology. He said that is makes more sense to first invest in improving the uranium-cycle, which can be made 50 times more efficient by using Fast Neutron Reactor. Koen Binnemans of the KU-leuven, and Mark O’Donnovan of Foratom state that too much is unproven about the use of thorium, what is your reaction to this?

Extra questions

15. Governments are not lining up to develop this technology, so should it come from businesses? If so, which path should be taken?

Is there a role for business people in this line of work?

16. The LFTR is said to be cheaper than uranium reactors and possibly even coal. What can you say about this?

An argument that is mentioned is that there is no need for a large concrete dome to protect against steam explosion, but matters like building partially underground and an expensive piping system might increase prices.

Do you know where I can find a good cost comparison between the LFTR and other power plants?

Is there anything important I am forgetting?

Do you have further comments?

If I encounter additional hurdles/disadvantages for the LFTR, can I send you them to comment on?

Finally, do you know other experts that would be valuable for me to interview?

Interview questions nuclear chemistry expert

Introduce myself
For starters, thank you very much for consenting to this interview, there are not many experts on thorium so I greatly appreciate your cooperation.

Can I record the interview?

Do you have any questions before we get started?

Can I use your name and answers in my thesis?

Shall I send you the written-out interview?

The LFTR utilizes a parallel running chemical factory to continually cleanse the salt/uranium mixture. This is one of the LFTR’s aspects of which little is currently known. A demonstration reactor has been operational in the 1960’s in Oakridge, but here the salt/uranium mixture was cleansed in batches.

1. What can you say about the LFTR’s chemical factory?

2. What will this system look like? Has this been completely designed?

3. Which processes will be applied? Which of these still require much research?

4. How expensive are the processes that have to be applied? If this is unclear, can an indication be given? A most positive/-negative scenario?

5. The salt uranium mixture is very corrosive/aggressive, necessitating very durable materials to contain the mixture. A possibility is Hastelloy-N, and according to Dr. Kloosterman this would not have a large influence on costs, partly because piping in the LFTR is not under pressure so pipes don’t have to be as thick. What is your opinion on this?

What else can you add about the chemical aspect of the LFTR?

To conclude, are there general things you would like to add about the LFTR?

**Interview questions Marieke van der Werf**

Thank you for cooperating with my thesis research. It is about the advantages and disadvantages of nuclear power based on thorium in the Liquid Fluoride Thorium Reactor. Are you familiar with the supposed benefits of this method?

Can I record the interview?

Do you have any questions before we get started?

Can I use your name and answers in my thesis?

Shall I send you the written-out interview?

1. I am very interested in Dutch/CDA energy policy. Could you tell me more about the reasons that led to the current policy on thorium and what this is based on?
- Do you know how other parties view this subject?

2. Another important aspect of my research is that I map who the stakeholders are in the development of this technology, and what their arguments are. These are scientists, companies, lobby-groups, press, politicians, and others that still have to be identified. Who or what do you consider important stakeholders?

3. Do you have contacts in other parties with a clear opinion on developing thorium that I can approach for an interview?

Am I forgetting something important?
Do you have any other comments?

Interview .... (stakeholders)24

Thank you for cooperating with my thesis research. It is about the advantages and disadvantages of nuclear power based on thorium in the Liquid Fluoride Thorium Reactor.

Can I record the interview?
Do you have any questions before we get started?
Can I use your name and answers in my thesis?
Shall I send you the written-out interview?

1. Are you familiar with the supposed advantages of thorium based nuclear power in the Liquid Fluoride Thorium Reactor?

2. If so, what is … stance on this technology, and what is it based on?

3. Is cleaner, safer nuclear power an option for your organisation? Why (not)?

4. Are you familiar with the WAMSR

5. Who do you consider to be important stakeholders in the development of the LFTR in the Netherlands?

Am I forgetting something important?
Do you have any other comments?
Shall I send you the research when it is ready?

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24 The same interview format was used for all stakeholders except the politician
B. e-mail information

Additional questions Dr. Jan Leen Kloosterman (Properties of the LFTR - additions)

#1

Hallo Lucas

Zie mijn antwoorden in het stuk.

groeten

Dr. Jan Leen Kloosterman
Associate Professor of Nuclear Reactor Physics
Director of Education Sustainable Energy Technology (SET)
Head of Section Nuclear Energy & Radiation Applications (NERA)

Delft University of Technology
Reactor Institute Delft / NERA
Mekelweg 15, NL-2629 JB Delft
Phone: +31 15 278 1191
E-Mail: J.L.Kloosterman@tudelft.nl
Homepage: www.JanLeenKloosterman.nl

-----Original Message-----
From: Pool LM, Lucas [mailto:l.m.pool@st.hanze.nl]
Sent: maandag 20 mei 2013 12:17
To: Jan-Leen Kloosterman - TNW
Subject: Vragen n.a.v. interview 24 april

Geachte heer Kloosterman,

Ik ben inmiddels een stuk verder maar er zijn nog een aantal punten waar ik vragen bij heb en ik hoop dat u die kunt beantwoorden. U kunt de antwoorden onder de vragen zetten als u dat handig vindt:

- U zei dat een reden dat het onderzoek nog minimaal 15 jaar duurt is dat er (bijvoorbeeld voor het testen van staal) aan hoge (veiligheids-)eisen moet worden voldaan. De reactor die in Oak Ridge draaide gebruikte Hastelloy-N dat in principe volstond, maar tegenwoordig zijn de eisen hoger en moet er dus opnieuw naar worden gekeken. Zou het kunnen dat in een land als China bepaalde (veiligheids-)eisen lager zijn (zoals in Amerika ten tijde van de Oak Ridge reactor) waardoor het proces sneller gaat? Of duurt bijvoorbeeld het onderzoek naar de “chemische fabriek” ook nog 15 jaar waardoor snellere test-procedures niet uitmaken? Wat zijn precies de redenen dat onderzoek nog 15 jaar duurt?

Antw: De MSRE in Oak Ridge had nog maar weinig “chemie” aan boord. Bij bescheiden temperaturen zal Hastelloy-N wel volstaan, maar je wilt uiteindelijk naar een echte centrale die werkt op hogeretemperaturen en met meer chemische zuivering van het zout. De processen en materialen voor die stappen kosten extra tijd.

- Ik las dat de LFTR o.a. tegen meltdown beschermd wordt door het uitzetten van de brandstof als de temperatuur stijgt, maar is meltdown in de eerste plaats al niet onmogelijk omdat de brandstof al gesmolten is? Als meltdown nog wel mogelijk is in de LFTR, hoe zou dat dan werken?

Antw: Het uitzetten van het zout beschermt tegen een onverwachte excursie van het splijtingsproces, niet tegen een meltdown. Het is een beetje flauw om te zeggen dat een meltdown niet mogelijk is omdat het zout al is gesmolten. Dat argument gebruik ik altijd als grapje in voordrachten. Waar het om gaat is dat het zout niet te heet wordt zodat alle materialen van de “eerste beschermlijn” in tact blijven en er nooit radioactief zout kan weglekken. Daarvoor zit de “freeze plug” gemonteerd waardoor het zout bij oververhitting naar opslagtanks kan stromen die door natuurlijke convectie met lucht kunnen worden...
gekoeld.

- Als argument voor het goedkoper zijn van de LFTR wordt het onnodig zijn van een grote betonnen koepel genoemd. (die normaal stoom van een stoomexplosie tegen moet houden) U dacht dat dit geen grote invloed op de kosten zou hebben omdat er toch iets tegen aanvallen van buitenaf zou moeten worden gebouwd. Maar kan dit niet op veel kleinere schaal, als het niet bestand hoeft te zijn tegen een explosie van binnenuit en al dat stoom binnen hoeft kunnen te houden?

Antw: de impact van een vliegtuigexplosie is zo groot dat de koepel toch nog wel behoorlijk stevig moet zijn

- De enige schatting over hoeveel geld er nog in onderzoek moet worden geïnvesteerd is van Kirk Sorenson, hij noemt 1 miljard dollar. Dit lijkt me typisch iets wat moeilijk te zeggen is, maar wat denkt u hiervan?

Antw: moeilijk te zeggen.

- Ik kwam een bedrijfje tegen van 2 MIT studenten die een variatie op de MSR hebben bedacht die op nucleair afval loopt, de WAMSR. Wellicht interessant voor u:
  

  http://transatomicpower.com/products.php

Tot slot, ik heb een document bijgevoegd waarin het standpunt van stichting Laka (documentatie & onderzoekscentrum kernenergie) over thorium in staat. Het is niet erg goed geschreven vind ik maar van wat ik er van begrijp gaat het om andere typen reactoren dan de LFTR. Misschien is het interessant voor u om te kijken of wat daar staat klopt, en zo niet dan is het wellicht belangrijk dat u dat aankaart want dit is bijvoorbeeld weer waar WISE (World Information Service on Energy) haar mening op baseert. Dit is overigens geen verzoek van mij om hier tijd aan te besteden voor mijn onderzoek, maar gewoon als interessant voor uzelf.

Antw: hartelijk dank.

Met vriendelijke groet,

Lucas Pool

#2

Zie mijn antwoorden in de tekst.

groeten

Dr. Jan Leen Kloosterman
Associate Professor of Nuclear Reactor Physics
Director of Education Sustainable Energy Technology (SET)
Head of Section Nuclear Energy & Radiation Applications (NERA)

Delft University of Technology
Reactor Institute Delft / NERA
Mekelweg 15, NL-2629 JB Delft
Phone: +31 15 278 1191
E-Mail: J.L.Kloosterman@tudelft.nl
Homepage: www.JanLeenKloosterman.nl

-----Original Message-----
From: Pool LM, Lucas [mailto:l.m.pool@st.hanze.nl]
Sent: zondag 2 juni 2013 23:29
To: Jan-Leen Kloosterman - TNW
Geachte heer Kloosterman,

Ik ben nu bijna klaar maar heb nog een aantal vragen en zou het zeer op prijs stellen als u me daar antwoord op kan geven. U kunt de antwoorden voor het gemak weer onder de vragen zetten.

- In ons gesprek zei u dat het ontwikkelen van een test reactor nog 15 jaar zou, maar op uw site staat “binnen 10 jaar”. Wat is juist en waarom?

Een testreactor zonder chemische fabriek (voor zuivering van het zout) kan binnen 10 jaar, met chemie duurt het 15 jaar.

- Een van de redenen dat het nog zeker 15 jaar duurt is dat de regels zijn aangescherpt sinds de test-reactor in Oak Ridge draaide. Zou het kunnen dat in een land als China, waar wellicht andere (minder strenge) regels gelden ontwikkelingen sneller gaan? Of heeft de chemische fabriek alleen al nog 15 jaar nodig?

Het zit hem denk ik vooral in de chemie en materiaalkwalificatie.

- Het grafiet dat in de LFTR gebruikt wordt moet elke 20 jaar worden vervangen, hoe veel extra radioactief afval levert dit op en hoe lang moet het worden opgeslagen? Maakt dit de LFTR minder “schoon” of was dit grafiet al meegenomen in het totale afval dat de LFTR zou produceren?

Het grafiet moet wel worden vervangen maar is niet of nauwelijks radioactief besmet. Het moet worden vervangen vanwege de stralingsschade die het gedurende de bestraling oploopt.

Volgens Robert Hargraves en Ralph Moir bestaat het LFTR afval voor 83% uit materiaal dat in 10 jaar veilig is, 87% uit materiaal dat in 300 jaar veilig is, en 0.01% plutonium. Over het plutonium heb ik een aantal vragen:

- Hoe lang moet dit plutonium worden opgeslagen?

Plutonium moet je eigenlijk hergebruiken. Als je dat niet doet moet je het circa 200.000 jaar opslaan.

- Er wordt vaak gezegd dat LFTR afval maximaal 300 jaar moet worden opgeslagen, maar op uw site las ik 500 jaar. Hoe zit dit? Is dit dan het grootste gedeelte van het afval met uitzondering van het plutonium, of zit het plutonium daar bij in?

De spliffingsprodukten blijven 300 jaar radiotoxisch. Ik heb aangenomen dat er ook nog sporen van actindien in het afval zitten en heb daarom 500 jaar aangegeven. Dit is geen wezenlijk verschil.

- Ik las op uw site dat een reactor met het vermogen van Borssele 500 KG thorium per jaar zou verbranden. Klopt het dan dat zo’n centrale maar 50 gram plutonium afval per jaar zou produceren?

ja

Heeft u nog kans gezien om dat document van Stichting Laka te bekijken? Zo ja, wat vond u daarvan?

Met vriendelijke groet,

Lucas Pool

E-mail ministry of economic affairs

Beste Lucas Pool,


Wij houden ons dus niet bezig met beleid, en vooral niet met keuzes wat betreft de wenselijkheid van verschillende typen kerncentrales en eventueel ondersteunen van onderzoek naar welke vorm van energieopwekking dan ook.

Dit laatste is de taak van de Directie Energiemarkt (EM), ook onderdeel van het ministerie van
Economische zaken.

Kijk voor een duidelijke beschrijving van de taakverdeling naar onderstaande link, en klik op Directie Energiemarkt, en Programmadirectie Nucleaire Installaties en Veiligheid.


1. Dit type reactor is bekend bij het ministerie van EZ. Behalve de voordelen is het ook bekend dat dit type reactor nog in de kinderschoenen staat wat betreft onderzoek en ontwikkeling, en dat er nog een hoop vraagtekens zijn over (eventuele) nadelen.

2. Het standpunt van het ministerie over kernenergie is vastgelegd in een brief aan de tweede kamer van 11-02-2011. Hierin is vastgelegd dat NL in principe open staat voor een nieuwe nucleaire centrale, mits aan bepaalde randvoorwaarden is voldaan. Betreffende de LFTR is met name het 1e punt van de randvoorwaarden van toepassing:

   “1. Het ontwerp van de kerncentrale moet gebaseerd zijn op de laatste stand van de techniek. Thans betreft dat de derdegeneratierreactoren. Het betreft dus geen reactoren die zich nog in ontwikkelings- of experimentfase bevinden.”

Ook iets eerder, onder het kopje “Rol overheid” is het volgende opgenomen:
“De elektriciteitsmarkt is geliberaliseerd en de Rijksoverheid investeert niet zelf, maar stelt randvoorwaarden. Binnen de randvoorwaarden is het aan de marktpartijen om al dan niet te investeren in kernenergie.”

NL zal dus volgend zijn in kernenergie, en niet leidend.

3. De NRG-notitie is dus niet het rapport waarop onze mening wat betreft de LFTR is gebaseerd. Het geeft een referentiekader betreffende thorium in het algemeen, en is dus van toepassing op elke reactor die thorium gebruikt (dus ook de LFTR), maar is slechts een beperkt onderdeel van het plaatje.

Mocht een partij een bepaalde reactor in NL willen bouwen, dan zal de vergunningaanvraag door minEZ behandeld worden. Mocht aan alle voorwaarden zoals beschreven in de randvoorwaardensbrief worden voldaan, dan zou de NL staat in principe een vergunning verlenen. Zoals je zelf kunt afleiden uit bovenstaande, voldoet de LFTR momenteel zeker niet aan de randvoorwaarden.

Voor wat betreft onderzoek naar de LFTR kan ik je verwijzen naar Jan-Leen Kloosterman, hoogleraar bij de Technische Universiteit Delft, en hoofd van de groep “Nuclear Energy and Radiation Applications”. Binnen deze groep wordt onder andere aan de LFTR onderzoek gedaan, en hij kan jullie meer vertellen over Europese ontwikkelingen, en waar onderzoeksgeld voor kernreactoren vandaan komt.


Ik hoop je hiermee beter geïnformeerd te hebben. Mocht je nog meer vragen hebben mail gerust. Ik zie niet direct een meerwaarde voor een interview, want ik denk niet dat we heel veel meer antwoorden hebben over de LFTR, maar mocht je behoefte hebben kunnen we denk ik het beste denk ik een telefoongesprek regelen.

Mvg,
Gert Jan Auwerda
C. Literature credentials

**Sigma Xi**

“The international honor society of science and engineering, Sigma Xi has nearly 60,000 members who were elected to membership based on their research potential or achievements. More than 500 Sigma Xi chapters in North America and around the world provide a supportive environment for interdisciplinary research at colleges and universities, industry research centers and government laboratories. More than 200 members have won the Nobel Prize.” (Sigma Xi, 2013)

**Robert Hargraves**

Dr. Robert Hargraves “…teaches energy policy at Dartmouth’s Institute for Lifelong Education. He was Chief Information Officer at Boston Scientific Corporation from 1994-2000, and a senior consultant at Arthur D. Little from 1982-1994. Previously he taught mathematics and introduced computer science at Dartmouth College, where he also founded a software company that sold the Dartmouth Time Sharing System. Dr. Hargraves earned his doctorate in physics from Brown University in 1967 and an AB in Mathematics and Physics from Dartmouth College in 1961.” (Flibe Energy, 2013)

**Ralph Moir**

Dr. Ralph Moir “…is a retired plasma physicist and nuclear engineer from the Lawrence Livermore National Laboratory and is an expert in hybrid fission-fusion reactors, particularly those that use molten salts for the blanket and first wall of the reactor. Dr. Moir has had 169 publications and five patents awarded in a variety of subjects related to fusion reactor technology. Dr. Edward Teller’s final paper (in 2005) was written with Dr. Moir on the subject of molten-salt reactors using thorium. Dr. Moir earned his doctorate in nuclear engineering from the Massachusetts Institute of Technology in 1967 and a BS in Engineering Physics from the University of California at Berkeley in 1962. He is a Registered Professional Nuclear Engineer in the State of California, Registration number NU782, a fellow of the American Physical Society and American Nuclear Society.” (Flibe Energy, 2013)

**Elsevier**

“...the world’s leading provider of science and health information, Elsevier serves more than 30 million scientists, students and health and information professionals worldwide. We partner with a global community of 7,000 journal editors, 70,000 editorial board members, 300,000 reviewers and 600,000 authors to help customers advance science and health by providing world-class information and innovative tools that help them make critical decisions, enhance productivity and improve outcomes.” (Elsevier, 2013)

**NRG**

“NRG (Nuclear Research and consultancy Group) is the nuclear service provider in the Netherlands. Our products and internationally renowned expertise are frequently called on by both governments and industries. NRG is operator of the HFR (High Flux Reactor) in Petten...” (NRG, 2013)

**National Nuclear Laboratory**

“The UK’s National Nuclear Laboratory (NNL) offers an unrivalled breadth of technical products and services to our customers across the whole nuclear industry. Covering the complete nuclear fuel cycle from fuel manufacture and power generation, through to reprocessing, waste treatment and disposal and including defence, new nuclear build and Homeland Security, NNL provides these services supported by an impressive range of links with international research organisations, academia and other national laboratories... NNL currently has 800 highly qualified staff with over 50% having 1st degrees, and over 20% having PhD’s.” (European Nuclear Society, 2010)

**NASA**

“Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) program plays a key part in helping NASA maintain
D. Additions to main body

**LFTR in more detail**

The core consists of fissile uranium-233 tetra-fluoride in molten fluoride salts of lithium and beryllium within a graphite structure that serves as a moderator and neutron reflector. The blanket contains a mixture of thorium tetra-fluoride, also in a fluoride salt containing lithium and beryllium, made molten by the heat from the core. The uranium-233 is produced in the blanket from thorium-232 when neutrons generated in the core are absorbed by the thorium-232 in the blanket, turning it into thorium-233 which decays to short-lived protactinium-233, which then again decays to fissile (capable of fission) uranium-233. This fissile material is then chemically separated from the blanket salt to the core to be “burned up” as fuel. The “burning” of this uranium-233 generates heat for power production and more neutrons that are used in producing more uranium-233 in the process described above.

(Hargraves & Moir, 2010, p. 307)

**Estimated world thorium resources**

Table 1: Estimated world thorium resources (World Nuclear Association, 2013)

<table>
<thead>
<tr>
<th>Country</th>
<th>Tonnes</th>
<th>% of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>India</td>
<td>846,000</td>
<td>16</td>
</tr>
<tr>
<td>Turkey</td>
<td>744,000</td>
<td>14</td>
</tr>
<tr>
<td>Brazil</td>
<td>606,000</td>
<td>11</td>
</tr>
<tr>
<td>Australia</td>
<td>521,000</td>
<td>10</td>
</tr>
<tr>
<td>USA</td>
<td>434,000</td>
<td>8</td>
</tr>
<tr>
<td>Egypt</td>
<td>380,000</td>
<td>7</td>
</tr>
<tr>
<td>Norway</td>
<td>320,000</td>
<td>6</td>
</tr>
<tr>
<td>Venezuela</td>
<td>300,000</td>
<td>6</td>
</tr>
<tr>
<td>Canada</td>
<td>172,000</td>
<td>3</td>
</tr>
<tr>
<td>Russia</td>
<td>155,000</td>
<td>3</td>
</tr>
<tr>
<td>South Africa</td>
<td>148,000</td>
<td>3</td>
</tr>
<tr>
<td>China</td>
<td>100,000</td>
<td>2</td>
</tr>
<tr>
<td>Greenland</td>
<td>86,000</td>
<td>2</td>
</tr>
<tr>
<td>Finland</td>
<td>60,000</td>
<td>1</td>
</tr>
<tr>
<td>Sweden</td>
<td>50,000</td>
<td>1</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>50,000</td>
<td>1</td>
</tr>
<tr>
<td>Other countries</td>
<td>413,000</td>
<td>8</td>
</tr>
<tr>
<td><strong>World total</strong></td>
<td><strong>5,385,000</strong></td>
<td></td>
</tr>
</tbody>
</table>

*OECD NEA & IAEA, Uranium 2011: Resources, Production and Demand (“Red Book”), using the lower figures of any range and omitting ‘unknown’ CIS estimate.*

(World Nuclear Association, 2013)
E. Detailed stakeholder list

The natural environment

Many types of industry negatively affect their environment in some way or other, but nuclear energy is especially notorious in this respect. Nuclear waste is one of the most dangerous types of industrial waste because of the disastrous effects high doses of radiation can have and the long time it remains hazardous. The LFTR also produces this kind of nuclear waste, be it far less than what traditional reactors produce.

Therefore one could argue that the LFTR, being a type of nuclear power plant, has a negative effect on its surroundings due to the waste it produces. On the other hand, one could argue that although it does produce nuclear waste, it is a fraction of what traditional reactors produce, and assuming that countries are going to continue employing nuclear power this is a huge improvement for the environment.

In addition to pollution being bad for the environment, it also influences the opinions of citizens and policy makers, making it one of the main reasons nuclear energy is not always supported. This is a key factor for the LFTR, because without support the technology cannot be developed. If people were to welcome the advantage of a fraction of the nuclear waste you would otherwise get instead of seeing all nuclear power as taboo, this would be a big step towards broader support for this technology.

What is needed to achieve this is that people can form their own balanced opinion on the matter. The truth is that most people, including politicians and civil servants, are not really informed about these issues, and some have never even heard of it (van der Werf, 2013). More, easy to understand, reliable research into the LFTR could be a solution.

The (Energy)-Economy

The LFTR is claimed to be able to produce large amounts of electricity, at a lower cost than traditional nuclear power and possibly even coal. This would have important implications for energy production and with that for the entire economy, because electric power is required for countless processes so cheaper power equals cheaper production, making businesses more competitive.

A cheap relatively clean energy source will also influence existing sources of power generation like coal, gas, traditional nuclear power, etc., and especially the “cleaner” sources of energy like renewables, if the LFTR is perceived as relatively clean by the general public.

Future generations

Future generations will be impacted by the decisions we make today.

If the LFTR is an unacceptable source of pollution we are burdening future generations with the waste we produce today, but if traditional nuclear energy will continue to play a role in the decades to come they might benefit from the reduced amount of waste the LFTR produces, the safer reactor design, and its other supposed benefits.

They are also affected by the energy aspect of the LFTR. If it does indeed turn out to be a competitive new source of relatively clean energy it might have added to their continued prosperity, while deciding not to develop the technology might deprive them of this opportunity. A third option would be that the technology is developed but does not live up to its expectations, which would mean a waste of resources.

Citizens

Citizens are important stakeholders because they benefit from the LFTR’s benefits like cheap electricity, safer reactors, and reduced waste, but suffer from its pollution.

Their opinion exerts considerable influence on policy makers and through them on the development of this technology. Some citizens like Henk Berendsen are pursuing the development of the LFTR themselves, in his case by contacting politicians to inform them about the technology (Berendsen, 2013).
A letter from the Dutch Minister of Economic affairs states that in the Netherlands, citizens perceive nuclear power as “(...) dangerous, but also necessary”. The subject of nuclear power is associated with fear, knowledge, and trust. (Verhagen, 2011)

**Scientists**

Scientists have a big stake in the development of the LFTR because it is up to them to provide the information to convince citizens and policy makers that this is a technology that we should pursue or not, and they are of course responsible for developing the technology.

A major issue with this technology are its unknowns, people cannot be expected to develop a well-funded opinion if the information is not brought to them, or is not there at all.

**Research institutions/universities.**

Because of the large investments in terms of manpower, funding, and other assets required, research is likely to take place at universities and other research institutions. This means research to further develop the technical aspects of the LFTR, at places like the Delft University of Technology, but also research into how to get the technology into the mainstream and convince policy makers of its benefits, at places like the Hanze University of applied sciences.

**Governments/the Netherlands**

Governments are the most likely candidates for leading the effort to develop the LFTR. Large investments in terms of manpower, funding, and other assets are required that call for a coordinated effort on a national level.

National governments might not even suffice however, especially with smaller countries. In Europe, the European Union would be best suited for making the investments that are needed. This is currently not happening however because member states like Germany, Denmark, and Austria are strongly opposed to any form of power generation based on nuclear fission (Kloosterman, 2013).

Politicians Politicians have influence on energy decision making and can be influenced by their constituency. M. van der Werf, former member of the Dutch house of representatives for the CDA (Christen Democratisch Appèl ) and spokeswoman for energy matters, was interviewed to get the “politicians”, and the CDA’s view on the LFTR.

The “Partij van de Arbeid (PvdA)” (Labour Party) and “Groenlinks” were approached about the LFTR by Mr. Berendsen. The labour party was of the opinion that this technology is too long term to be of interest to them, and Groenlinks is against nuclear power (Berendsen, 2013). M. van der Werf mentioned that the “Volkspartij voor Vrijheid en Democratie (VVD)” is positive about the use of nuclear power (van der Werf, 2013).

**Civil servants (Ambtenaren)**

Perhaps even more important than politicians, are civil servants working at the ministries. They are responsible for determining policy in the end so their opinion is vital.

Tafel Industrie, grootschalige energieproductie en ETS

M. van der Werf said in her interview that to get an overview of the stakeholders in the decision making process for energy matters in the Netherlands, one has to look at the members of the “Table for industry, large-scale energy production and Emission Trading Systems” (Tafel Industrie, grootschalige energieproductie en ETS (SER, 2013)). This “table” is a consultative body for representatives of umbrella organisations that have a say in energy matters, from energy producers to lobby groups, and it is where Dutch energy policy is made (van der Werf, 2013).

To know whose opinions would need to be influenced to work towards the development of the LFTR, these are the people and organisations to look at. Ms. van der Werf also said that she believes the word thorium is not mentioned at this table at all, so perhaps much ground could be won with simply informing these organisations.

Member of the Tafel industrie, grootschalige energieproductie en ETS are:
Hans Alders (Energie Nederland) Energie Nederland represents the interests of nearly all energy companies on the Dutch market, including producers, traders, and distribution.

Monique van Eijkelenburg (DE-Koepel) Duurzame Energie Koepel, is an organisation that represents the interests of the Dutch sustainable energy sector.

Marten van der Gaag (IPO) Interprovinciaal Overleg represents the interests of the provinces by exerting influence on national environmental legislation, to ensure it remains feasible for the provinces.

Alexander de Roo (IPO) Interprovinciaal overleg.

Reiner Gerrits (VNCI/VNPI) The Vereniging Nederlandse Petroleum Industrie represents the interests of petroleum companies in the Netherlands.

Frits de Groot (VNO-NCW en MKB Nederland) VNO-NCM is the largest organisation of businesses in the Netherlands, representing about 115,000 businesses, and 90% of all employment.

Hans Grünfeld (VEMW) De Vereniging voor Energie, Milieu en Water (VEMW) represents the interests of business water and energy consumers.

Diederik de Jong (Min. I&M) Ministry of Infrastructure and Environment

Rens Knecht (Netbeheer Nederland) Netbeheer Nederland is the representative of all electricity-, and gas-infrastructure businesses.

Hans Koning (Min. Financiën) Ministry of finance

Joop Oude Lohuis (De Groene Zaak) Organisation promoting sustainability in business.

Marina Nolle (CNV Publieke Zaak) Labour union representatives

Pim de Nijs (CNV Vakcentrale) Labour union representatives

Margreet Pasman (FNV bondgenoten) Labour union representatives

Cock Pietersen (FME) Employer’s organisation for the technological industry
Geert Ritsema (Milieudefensie) Organisation representing environmental interests, focusing on the themes: International, traffic and sustainable food.

Joris Thijssen (Greenpeace) Lobby group for environmental protection issues

Rob van der Valk (LTO) Land en tuinbouw organisatie, entrepreneur and employer organisation for agricultural businesses.

Tjalling de Vries (Min. EZ) Ministry of Economic Affairs, Agriculture, and Innovation

The Ministry of Economic Affairs’ current stance on nuclear power has been described in a letter from the minister of Economic Affairs, to the House of Representatives from 11/02/11. The letter states that although the Netherlands is open to new nuclear power plant construction, these have to adhere to certain preconditions. Precondition 1 states that:

“1. The nuclear power plant design has to be based on the latest technology. At present those are the 3rd generation reactor designs. This excludes reactors that are still in the development- or experimental phase.”25 (Verhagen, 2011)

The LFTR is still very much in the development/experimental phase and therefore does not meet this criterium.

In addition to that the Dutch government does not invest in nuclear technology directly. They leave it to private sector parties to invest in new nuclear power plants, provided that they meet the preconditions described in the letter to the House of Representatives. The Dutch government does not intend to take the initiative on nuclear power development but will take a reactive stance (Auwerda, 2013).

Ron Wit (Natuur & Milieu) Organisation promoting sustainability.

Local governments

Local governments are influenced when it would come to actually building a LFTR. Some municipalities might be opposed to having a reactor built while others might welcome the opportunity.

Companies

There is a range of companies that would be influenced by, or could have influence on developing this technology.

Energy producers - competitors

Renewables

The renewable energy sector would be strongly influenced by the development of this technology if the public accepts it as “green”, or close enough to not have too big an impact on the environment relative to its benefits. If renewables see a strong development which enables them to provide enough power at a reasonable efficiency, the LFTR might be less attractive.

Nuclear power

Traditional forms of nuclear power might become obsolete if the LFTR lives up to its expectations. Other forms of nuclear power might also emerge that make the LFTR obsolete.

Oil

The powerful oil industry could view LFTR development as a form of competition but could also see
Oil companies are already diversifying by investing in renewable energy technologies and the LFTR could become part of that portfolio (Chevron, 2013).

**Coal**

Coal electricity plants are generally viewed as highly pollutant, but are still being built and operated because of the cheap electricity it produces (Union of concerned scientist, 2012). The LFTR could be a dangerous source of competition to this industry.

**Gas**

Natural gas is cleaner than coal but more expensive. If the LFTR would turn out to produce cheaper electricity and be perceived as clean by the general public, it could be a dangerous competitor (naturalgas.org, 2011).

**Thorium production, mines, etc.**

An entire new industry will open up if thorium becomes a fuel. Currently thorium is seen as a useless by-product from other forms of mining, which has to be dealt with at some cost. It is so abundant that it is not very attractive as a source of revenue but this might well change if it is used on a large scale (Lifton, 2009).

**Uranium production, mines, fuel fabrication, enrichment, etc.**

Conversely, the rise of thorium could be disastrous to the uranium industry. If LFTR’s would turn out much better suited for power generation than uranium burning reactors, these might well be replaced. How long this would take is difficult to say, but uranium reactors that have already been built will likely be kept operational to avoid capital destruction, unless there is a popular call for their shutdown. If they remain active a demand for uranium will exist for some time, but will probably decrease. There could be resistance to developing the LFTR coming from this industry, which at the moment has considerable power due to it being the only form of nuclear energy.

**Thorium power developers**

There are a number of companies that are attempting to develop thorium power commercially:

**Flibe Energy**

Company that aims to develop LFTR’s. Founded by Kirk Sorenson, one of the LFTR’s most outspoken and well-known advocates and creator of the energyfromthorium.com web page (Flibe, 2013).

**Thor energy**

Norwegian company that advocates the use of thorium and produces thorium fuel for the Light Water Reactor, but not the LFTR. Wants to capitalize on thorium’s abundance (in Norway) (Thor Energy, 2013).

**Thorium Power Canada Inc.**

Company that develops thorium reactors (Thorium Power Canada Inc., 2013).

**Thorium Energy Generation Pty. Ltd.**

Australian company dedicated to developing the Accelerator Driven Sub-critical (ADS) thorium power generation systems (Thorium Energy Generation Pty. Limited, 2013).

**Trans-atomic Power**

Not a company that develops a purely thorium based reactor, but one that deserves honourable mention because they improved the Molten Salt Reactor design. 2 Massachusetts Institute of Technology (MIT) students have developed an improved version of the LFTR that they call the Waste Annihilating Molten Salt Reactor (WAMSR). As the name suggests, the reactor runs on old nuclear (uranium) waste, and turns it into energy, and a fraction of the original waste that is safe after a couple of hundreds of years, but being a molten salt reactor, it could also run on thorium. The company
expects commercial reactors to come online in 20 years. It does not intend to build reactors themselves but to license its technology (Martin, 2012) (Transatomicpower, 2012).

**Lightbridge**

American company developing nuclear fuels and providing advisory services. Also has a thorium-based fuel solution in its portfolio (Lightbridge, 2013).

**Potential private sector financiers**

**Bill Gates**

Bill Gates, founder of Microsoft and billionaire, has stated that he wants to invest in energy. He talked about an energy portfolio of 5 technologies and although he invests directly into a reactor design called “The Travelling Wave Reactor”, this design could also be used to burn thorium. He says in his TED-talk that innovation in nuclear technology has stopped a while ago and mentioned liquid nuclear reactors as one of the possibilities: “There are some innovations in nuclear, there is modular, there is liquid, and innovation really stopped in this industry quite some time ago, so the idea that there are some ideas laying around is not all that surprising” (Bill Gates on energy: innovating to zero!, 2010) (International Thorium Energy Organisation, 2010).

**Google**

Google is taking a strong interest in energy technologies and they have hosted the Thorium Energy Alliance Conference (TEAC) in 2010 (TEA, 2010). In addition to that, Google-tech talks have been given by Kirk Sorenson of FLiBe energy in 2009 (Energy from thorium: a nuclear waste burning liquid salt thorium reactor, 2009), 2011 (The thorium molten salt reactor: why didn’t this happen, 2011) and in 2009 by David LeBlanc (Liquid fluoride reactors: a new beginning for an old idea, 2009).

**Thorium developing countries/governments**

**India**

India is working on developing thorium but uses the Advanced Heavy Water Reactor rather than the LFTR. India’s interest in developing thorium as a nuclear fuel is likely to be less about safety and reduced waste than it is about energy independence due to the fact that the country has one of the world’s largest supplies of thorium within its borders, (Kloosterman, 2013) (Hodson, 2012) but no uranium. What is more, India has not signed the Non Proliferation Treaty and therefore “isolated from the broader international nuclear R&D community” (National Nuclear Laboratory, 2012).

**China**

China is leading the way in Molten Salt Reactor development, in 2011 they announced their intention of developing a thorium based molten salt reactor in 20 years (news356.com, 2011). The project is headed by Jiang Mianheng, son of the former Chinese president Jiang Zemin and has a start-up budget of $350MLN, and 140 PhD scientists working on it. This number is to be increased to 750 scientists by 2015 (Pritchard, 2013) (Hart, 2011).

**United States of America**

A partnership is said to exist between China and the United States on developing Molten Salt Reactor technology. U.S. assistant energy secretary Peter Lyons is co-chairing the executive committee of this partnership with Jiang Mianheng, which includes members from U.C. Berkeley, Oak Ridge National Laboratories, Massachusetts Institute of Technology, and Idaho National Laboratory (Halper, 2012).

**Norway**

The before mentioned “Thor Energy” is collaborating with the Norwegian government and the U.S. based “Westinghouse”, a company that develops nuclear power plants among other things (Westinghouse, 2013). The reactor that is used is a Heavy Water Reactor and not a LFTR so it is not ideal for using thorium as a fuel, but its advantage is that it has already received regulatory approval, and can be used to demonstrate some of thorium’s benefits to the world (Murray, 2012). Norway also has the largest thorium reserves in Europe which makes developing thorium as a fuel interesting to them (IAEA, 2008).
Japan

In 2012 Japanese utility Chubu Electric Power Co. announced plans to start researching the development of a Molten Salt Reactor in 2013 (Halper, 2012).

France

France depends for 75-80% of its energy on nuclear reactors. Grenoble based nuclear research laboratories have been working on Molten Salt Reactor development (Pottinger, 2011).

The Netherlands

Research into thorium and the MSR is being done at the Technische Universiteit Delft in the Netherlands (Kloosterman, 2013).

Russia

Russia has agreed to develop thorium- and fast neutron reactors in cooperation with India (The voice of Russia, 2013).

Lobby groups

Greenpeace

Greenpeace is one of the most well-known lobby groups for environmental and animal issues. They are strongly opposed to nuclear energy, but it is unclear what their stance on alternative nuclear technologies like the LFTR is. They were approached to be interviewed about this but refused (Greenpeace, 2013).

World Information Service Energy

The World Information Service Energy is an international network organisation that is strongly opposed to nuclear power (World Information Service on Energy, 2013) and believes investments should go towards truly sustainable sources of energy like solar and wind. They have a limited knowledge of the LFTR technology and recommended Stichting Laka for more information. What is more, P. de Rijk of WISE personally does not believe thorium will turn out to be as good as it sounds, but he did agree that if investments are going to continue to be made in nuclear energy, it would be better if they go towards the LFTR than uranium based reactor development.

This led to an interesting thought: what if organizations like WISE would take the position that no funding should go to nuclear energy, but if nuclear is going to be funded it should be the LFTR. That way, if it turns out not to be as good as it sounds it will mean a blow to the nuclear energy lobby, and if it does, there is a more sustainable alternative to uranium-based nuclear power (World Information Service on Energy, 2013).

Stichting Laka (Landelijk Kernenergie Archief/National Nuclear Power Archive)

Foundation documenting information about nuclear power and -weaponry that serves as the base of information for other anti-nuclear lobby groups (Stichting Laka, 2013). They were approached for an interview about their stance on thorium and the LFTR but indicated that their stance was described already in a document. This document was sent to the researcher but on closer inspection appeared not to be about the LFTR but about other types of thorium reactors. The document was sent to Dr. Kloosterman for further analysis.

Energy from Thorium Foundation

"US-based not-for-profit organization dedicated to advancing the research, development and deployment of safe, clean and affordable energy based on Liquid Fluoride Thorium Reactor technology (LFTR)” (Energy from Thorium Foundation, 2012) Spiritually led by Kirk Sorensen, LFTR proponent, former NASA Engineer, and Chief Technology Officer of Flibe Energy (Energy from Thorium Foundation, 2012).
International Thorium Energy Organisation (IthEO)

Organisation campaigning for the development and production of Thorium energy plants around the world (International Thorium Energy Organisation, 2013).

Military

The LFTR might well be of interest to the military because of the possibility of developing small versions that could be used to power machinery or provide electricity to military bases, but might also be viewed as undesirable because uranium fuelled reactors are more suited to producing material for nuclear weaponry.

Press

Because one of the LFTR’s main obstacles is its relative obscurity among the general public and policy makers, the press could be instrumental in realising the LFTR’s development. If policy makers would be better informed about its possibilities they might be more inclined to lobby for it, and if citizens would be more aware of its benefits they might exert more pressure on politicians. In recent years more and more is being written about the LFTR.
F. Stichting Laka’s stance on thorium

Published: February 2008

THORIUM-BASED NUCLEAR POWER: AN ALTERNATIVE?

It is said that the global reserves of thorium are considerably larger than natural uranium. Therefore the call for thorium-based nuclear energy is rising. In the past 50 years basic research and development on the use of thorium-based fuel cycles has been conducted in Germany, India, Japan, Russia, the UK and the USA. Test reactor irradiation of thorium fuel to high burn-ups has also been conducted and several test reactors have either been partially or completely loaded with thorium-based fuel. In 2007, a lobby for nuclear power based on the thorium cycle, forced the Norwegian government to consider the option and establish a Thorium Report Committee. In February 2008 the report of the Committee, entitled Thorium as an Energy Source – Opportunities for Norway, was released. The Committee notes “[that] Norway has one of the major thorium resources in the world, a potential energy content which is about 100 times larger than all the oil extracted to date by Norway, including the remaining reserves.” This sounds almost like the 1950s claim that 1 gram of ‘concentrated’ uranium, delivers the same amount of electricity as 100,000 kilos of coal. However, the authors also conclude that: “Due to a lack of data, it seems impractical to develop meaningful cost projections for any nuclear energy system using thorium. […] The main economical challenges to the development of a thorium based energy production will be the acquisition of funding necessary to carry out the required research and development.” On receiving the report, Norway’s minister of petroleum and energy, Åslaug Haga, said: “I register that the report neither provides grounds for a complete rejection of thorium as a fuel source for energy production, nor does it offer enough reason for embracing it as such. The government’s viewpoint has not changed, meaning that there exist no plans to allow construction of nuclear power plants in Norway.” Apparently financial and technical uncertainties in developing a thorium fuel cycle infrastructure have made the Norwegian government very careful to make a clear decision. Just as uranium thorium is a naturally occurring radioactive trace element found in most rocks and soils. It was discovered in 1828 by the Swedish chemist Jons Jakob Berzelius, who named it after Thor, the Norse god of thunder. Australia and India each have around one quarter of the world’s reserves, while both Norway and the United States have 15%. An international lobby is labeling thorium as a ‘safe’ alternative for uranium-based nuclear energy. The promoting experts point to a list of arguments that has to prove the advantages of thorium above uranium. However, can the supposed benefits of thorium pass the critical test? Relying on the most frequently used claim of the lobby on the abundance of thorium there are reasons enough for a thorough analysis of their arguments. The lobby always starts with an argument like this: “Thorium is about three times more abundant than uranium. Unlike natural uranium, containing 0.7% ‘fissile’ uranium-235, natural thorium does not contain any ‘fissile’ material and is made up of ‘fertile’ thorium-232 only.” This presentation is quite misleading, because it omits a comparison with the possible uses of uranium fuels and particular uranium-238, just like thorium-232 ‘fertile’, for Fast Breeder Reactors (FBRs). When the large scale development of FBRs was envisaged, the possibilities of using the ‘fertile’ uranium-238 were emphasized and were also believed to lead to infinite sources of energy. However, it is well-known that countless technical, political and economical problems have undermined the FBR development. Just like the non-fissionable uranium-238 isotope, thorium-232 can’t be split. Comparable to the uranium based fuel cycle in which uranium-238 is used to breed fissionable plutonium-239, the thorium based fuel cycle uses thorium-232 to breed fissionable uranium-233. Three stages can be distinguished (see: Thorium Cycle Scheme). In the first stage uranium-238 is converted into plutonium-239 in Indian CANDU reactors (PHWR), fed with natural uranium. In the second stage uranium-233 (and plutonium) is produced in a Fast Breeder Reactor (FBR) in which plutonium is the raw material and uranium and thorium are used as the blanket. Though not yet achieved the first stage, forerunner India has almost reached the second stage of this three-staged fuel cycle. Last November the Indian minister of state Prithviraj Chavan declared that India has extracted 30,000 tons of thorium concentrate to prepare for the third stage of the nuclear power program. Nuclear scientists expect the thorium-based third stage (see box) to begin only around 2030. One of the reasons why the more than fifty year old Indian indigenous nuclear power program is making a slow progress is the lack of uranium technology and fuel, needed to speed up the utilization of thorium. The Indo-U.S. deal has to solve these problems.

Experts from the thorium lobby now say that all aspects of the thorium-based nuclear energy
program can be technically achieved. The most important advantages according to the lobby are on the level of efficiency, proliferation, harmfulness and half-lifes of radioactive waste, and reactor safety. A Norwegian expert claims that thorium produces 250 times more energy per unit of weight than uranium in the present reactors. In addition the thorium lobby stresses that thorium fuel in contrast with uranium fuel doesn’t produce any plutonium and that the spent thorium fuel would be much less radioactive than ‘conventional’ nuclear reactors. Also they claim that the half-lifes of the radioactive waste products are in the range of hundreds of years instead of thousands of years in the case of ‘conventional’ spent nuclear fuel. Another often-used argument is that thorium reactors will not be based on moderated chain reactions like in ‘conventional’ nuclear reactors, but on accelerator-driven systems (ADS). ADS could be the third stage of the three-staged thorium based fuel cycle. However, India considers the Advanced Heavy Water Reactor (AHWR) as the first option. ADS consist of three main units: the accelerator, the target/blanket unit and the separation unit. The accelerator generates high energy charged particles which strike a heavy material target. This bombardment leads to the production of a neutron source, a process called ‘spallation’. The produced neutrons enter a subcritical core - often called a blanket - where they can be multiplied. Indeed, all of these claims sound attractive, but in fact these ‘advantages’ don’t pass the critical test. Criticasters states: in reality not 250 but some 40 times the amount of energy per unit mass – compared with uranium - might theoretically be available from thorium. Though less than claimed by the thorium-lobby, this still seems to be a high efficiency. However, the problem remains if this would be technically feasible. And, in theory the energy per unit mass is maybe even comparable in the case FBRs are used to breed fuel in the uranium based fuel cycle.

India: Thorium Cycle Scheme

reactor(s) fuel / blanket product(s)

Stage 1 PHWR(CANDU) natural uranium plutonium
Stage 2 Fast Breeder Reactor (FBR) plutonium / uranium-233 and thorium and uranium plutonium-239
Stage 3 Advanced Heavy Water thorium-232 uranium-233 Reactors (AHWR) uranium-233 thorium-232 plutonium plutonium

On proliferation: though it is important to note that a thorium reactor doesn’t produce any weaponsgrade plutonium, one needs to mention at the same time that the reactor does produce weaponsgrade uranium-233. In fact uranium-233 is even a more effective fissile material than uranium-235. It has the same significant quantity (SQ) as plutonium-239: an amount of 8 kg is sufficient to make a nuclear bomb. Therefore the waste from thorium reactors is still a security risk. There is only one remark: compared to plutonium-239 uranium-233 is somewhat more difficult to separate from the spent fuel. The main reason for that however, brings another disadvantage in the thorium-uranium fuel cycle to the surface: the high gamma radioactivity due to contaminants in recovered uranium-233, namely uranium-232 and thorium-228, both of which are neutron-emitters, reducing its effectiveness as a fuel and which is partly responsible for the high costs of fuel fabrication. Brian Johnson, a researcher from the Oregon State University, states more specifically on uranium-232 in a 2006 study sponsored by the American Nuclear Society: “Unfortunately if one assumes a closed fuel cycle, thorium has a disadvantage in that there are some highly penetrating radioactive materials, thallium-208 and bismuth-212, that are unavoidably created in the spent fuel. They occur as part of the decay of uranium-232 which cannot be separated chemically from the uranium-233 in the spent fuel.” These disadvantages make clear the difficulties in handling thorium based spent fuel and the purification of uranium-233 for re-use in the three-staged cycle. Except the handling of the material, these problems don’t play any role in the military use of
uranium-233. The fissile power of uranium-233 is not influenced by the contaminants. Finally, it is worth to note that because of these disadvantages the spent fuel of a thorium reactor is much more dangerous when used in dirty bombs. As noted above thorium reactors must breed their own nuclear fuel from uranium-233. The point is, however, that there is almost no separated uranium-233 anywhere in the world. In order to get it one has to start with for example plutonium-239 to get one reactor in operation. After 40 years this will have bred enough.

Thorium fuel cycle in India

In the early 1950s India started research and development efforts on the thorium / uranium fuel cycle and thorium-fuelled reactor programs. India can be considered as the main pioneer in developing the thorium fuel cycle and has several advanced facilities to this. The Indian authorities consider a closed nuclear fuel cycle of crucial importance for its three-stage nuclear power program with its long-term objective of tapping India’s vast thorium resources. In the front end of the cycle, the program is providing inputs to the indigenous Pressurized Heavy Water Reactor (PHWR) phase. This type of reactor is elsewhere known as CANDU, the Canadian heavy-water reactors fuelled by natural uranium. Though the long-term goal of India’s nuclear program is to develop a heavy-water thorium cycle, their PHWRs and lightwater reactors are currently used to produce plutonium. Hence, ‘fertile’ thorium and thorium-based fuel has to be utilized in combination with ‘fissile’ material (for now plutonium-239 or uranium-235) in order to breed ‘fissile’ uranium-233. Besides a breeding product this uranium-233 has to become also the feeding ‘fissile’ material in the future for the just described first stage of the aimed thorium-based nuclear fuel cycle in order to close this fuel cycle. The second stage in the fuel cycle uses fast breeder reactors (FBRs) burning the plutonium to breed uranium-233 from thorium. The blanket around the core will have uranium as well as thorium, so that further plutonium is produced as well as the uranium-233. Finally, in the third stage or the back end of the fuel cycle Advanced Heavy Water Reactors (AHWRs) are supposed to burn the uranium-233 and the plutonium with thorium, getting about two thirds of their power from the thorium, according to the lobby. Up to a few years ago the lobby mentioned a figure of 75 per cent. Despite the glorifying stories from Indian officials even the first stage of their indigenous nuclear energy program is not yet fully achieved. The two PHWR-units in Kakrapar were the first reactors (continued on page 4)

in the world that have tested thorium. In 1995, Kakrapar-1 achieved only about 300 days of full power operation and Kakrapar-2 about 100 days utilizing thorium fuel. More details are not available. In fact the first stage has not passed the laboratory scale. Irradiation of thorium fuel bundles takes place in a research reactor at Trombay. The use of thorium-based fuel on a
‘commercial’ scale is planned in Kaiga-1 and -2 and Rajasthan-3 and -4 reactors, which are currently under construction. Finally these thorium-based PHWRs can only become ‘commercial’ when India has sufficient resources of natural uranium to feed these PHWRs in order to get plutonium as the fissile material to start the thorium based nuclear fuel cycle.

After operating a fast breeder test reactor (FBTR) for two decades India is now on the brink of launching a commercial fast breeder program to take India’s ambitious thorium program to the second stage. India has vast reserves of thorium but modest amounts of uranium. Scientists at the Indira Gandhi Centre for Atomic Research, Kalpakkam, have said the conversion of thorium into uranium-233 fuel would depend on the rate of growth of the second-stage, fast-breeder reactors. Currently a 500 MW prototype FBR at Kalpakkam is under construction and is expected to become operational in about four years. It will have a blanket with thorium and uranium to breed fissile uranium-233 and plutonium respectively. Three more of such FBRs have been announced for construction by 2020. Other steps the Indian government has taken to develop appropriate technologies for the utilization of thorium are the setting up of the research reactor Kamini at Kalpakkam, operating since 1997, using uranium-233 fuel obtained from irradiated thorium, and the development of technologies to reprocess irradiated thorium fuel and in fabricating uranium-233 based fuel. According to Indian scientists the planned FBRs can use about 30 tons of thorium for conversion. The actual amount of thorium available for conversion from the 30,000 tons of thorium concentrate would depend on the level of concentration. A one per cent concentration would mean 300 tons while a 10 per cent concentration would mean 3,000 tons of thorium available for conversion. Thorium in India is mainly recovered from monazite, a naturally occurring mineral. Monazite is produced as a co-product along with substances such as ilmenite, zircon and rutile. In a recent interview the Indian minister of state Chavan said India needed to have international cooperation to acquire uranium technology and fuel, which was insufficient in the country. In a veiled reference to the Indo-U.S. deal he said: “The government is trying for international cooperation in this sector and also trying to convince the House to allow it to obtain uranium to speed up the process of atomic nuclear fuel.” [...] “If the government is allowed to go for international cooperation, there will be enough uranium available that will speed up our nuclear program much faster.” The encountered problems can’t be solved with the current reprocessing technology. Therefore new technologies and plants have to be developed. Lately, thorium-based fuel is named as a promising alternative for MOX-fuel to burn weapons grade plutonium. Through a joint operation between the Kurchatov Institute and Thorium Power Inc. funded by the US, a plutonium incinerating thorium-based fuel design for current reactors is “about two or three years from implementation in a reactor”, according to Thorium Power Inc. In 2006 in Brian Johnson’s 2006 study.. The author continues: “Thorium-based fuels could reach the disposition goal more than twice as fast as MOX in the same reactor.” This would mean that fewer reactors would be needed to burn the plutonium. At the same time he notes: “While MOX and thorium-based fuels have a great deal of data, it is difficult to get any hard data on how much plutonium can be disposed of per year using fast reactors.” Therefore it isn’t easy to make any conclusive statements on the value of thorium-based fuels for this purpose, when we restrict ourselves strictly to the available methods of burning plutonium. In fact there is not so much difference with the use of MOX and all the disadvantages connected to this as described in the past decades (reactor-safety, Pu-transport, Pu-fuelfabrication, proliferation-risks, etc) Further there are some disadvantages of thorium - when compared with uranium - that were recognized from the beginning, but now appeared to be almost forgotten: thorium is more radioactive than uranium, making its handling in fabrication stage more beset with dangers. In addition there are potential difficulties in the back-end of the fuel cycle. The plutonium-238 content would be three to four times higher than with conventional uranium fuels. This highly radioactive isotope causes a much higher residual heat and therefore the time for spent fuel storage in water is much longer. To put it mildly, the technical problems regarding the reprocessing of spent fuel is not solved for this reason. It would be a revolutionary step forward in nuclear safety if all nuclear reactors could be replaced by accelerator-driven systems (ADS) in the foreseeable future; there is no need to use a moderated chain reaction: a chain reaction that can get out of control, which could cause melt-downs. In addition the lobby claims that introducing ADS can reduce by at least 3 orders of magnitude the time needed for the geological disposal of nuclear wastes. The recent Norwegian study summarizes the advantages of an ADS fuelled by thorium, relative to a conventional nuclear power reactor, as follows, and states that such a system is not likely to operate in the next 30 years: There is a much smaller production of long-lived actinides, there is a minimal probability of runaway reaction, an
efficient burning of minor actinides and a low pressure system. The disadvantages are summarized as follows: more complex; less reliable power production due to accelerator downtime; the large production of volatile radioactive isotopes in the spallation target; and the beam tube may break containment barriers. This overview still gives a too optimistic view.

One has to keep in mind that the ADS is in an early testing stage. Even when ADS will succeed there are still problems such as the production of radioactive waste, as noted above. Though the system was named as a promising instrument to transmuted long-lived highly radioactive transuranic elements, the results are poor. Above this, there are other serious problems that could occur with thorium fuelled reactors. A wellknown example is the thorium high-temperature reactor (THTR 300) in the German municipal Hamm/Uentrop. The reactor has been out of operation since 1986. Besides the reactor building, the nuclear power plant has been demolished. Hamm/Uentrop was closed, because the company in charge of the plant was unable to control it properly and covered up numerous technical problems, such as serious problems with replacing the thorium fuel spheres. For those reasons one has to conclude that thorium is not a serious alternative for uranium. Even when India is able to solve the many hooks and eyes it would take many decades, if ever, before the full thorium cycle is large and reliable enough to be ‘commercial’, while the current problems with nuclear fission remain to exist. Just like ‘conventional’ nuclear power the technology can’t play any significant role in tackling the urgent problems connected with climate change.

Sources:
- World Nuclear News, 18 February 2008: “Norway’s thorium option ‘should be kept open’”
- The Telegraph, 22 November 2007: “Thorium stock for nuclear power”
  http://pib.nic.in/release/release.asp?relid=32981
- The Hindu 22 November 2007: “We won’t back out of nuclear deal”: Pranab Mukherjee.
- The Independent, 13 December 2006. Professor Egil Lillestol of the Intitute of Physics and Technology at the University of Bergen, Norway
  IAEA, Division of Nuclear Power, Nuclear Power Development Section, Vienna, Austria.
- Johnson, Brian;“Thorium for Use in Plutonium Disposition, Proliferation-Resistant Fuels for Developing Countries, and Future Reactor Designs” Oregon State University, Washington Internships for Students of Engineering (WISE) 2006

recommended literature:
Published: Nuclear Monitor, 21 February, 2008
G. Minutes supervisor meetings

Supervisor meeting 28/02/2013

How to proceed?  So far:

Advantages of thorium described as taken from AS article, some framework.

Next up:

LFTR breakdown, adding other sources’ info. Collecting and describing disadvantages. Info to be used to guide interviews. Proceed with secondary research according to Mallon’s criteria?

Interviews

Approach in such a way that not only do I get something from them, but I am of use to them too.

Thorium interviews

Jan-Leen Kloosterman

Americans? Kirk Sorenson, Robert Hargraves

Chinese?

Norwegians?

French

Belgians

Companies developing thorium reactors if there are any?

Gates

Google

Does Mr. Dommerholt have contacts that know about nuclear or other energy?

Does Win Mallon or DNV Kema have contacts I could interview?

Renewable energy interviews?

Public opinion

Greenpeace

Politici

Flexinet – How to follow up on Mallon’s research proposal?

GPJ-defense - Conny

Week 6&7 – Interviews China

Supervisor meeting 19/03/13

Attendees: Lucas Pool, Egbert Dommerholt

Letter to thorium experts
Is it done?
Whom to send it to?
What about signing: did lector agree & when do I sign?

Research proposal
Do I need a detailed list of sources?
Should project title be precise or can it be creative?
Is project description precise enough?

Stakeholders, national or international? International makes more sense, the Netherlands = unrepresentative example. What about consistency?

Do research philosophies in the onion apply to non-business research

Planning
Discuss planning
How to contact other stakeholder representatives for interviews? E-mail?

Other
Cum laude à sustainability repair?

Supervisor meeting 15/04/13
Attendees: Lucas Pool, Egbert Dommerholt

Letter to thorium experts
Interview Kloosterman 23/04

Research proposal
I am required to give recommendations to some party, who should that be exactly?

Planning
What about other stakeholder interviews?

Supervisor meeting 26/04/13
Attendees: Lucas Pool, Conny Dröge

Defense
Which time on the 18th of June will work? Reserve room, check w/ Mrs. Droge

Stakeholder list
Discuss options
Add cost estimate for LFTR

**Supervisor meeting 19/03/13**

Attendees: Lucas Pool, Egbert Dommerholt

Thorium experts

Interview Kloosterman (Should interviews be translated into English? Just the summary maybe? Should interviews be written out word for word?) JUST THE SUMMARY, WORD FOR WORD NOT NECESSARY

Do I need more experts?

Costs LFTR

Mrs. Droge requested cost estimate, J.K. thought none existed, ??? provided me with one from 2001 by Ralph Moir. How am I supposed to evaluate his estimates? Reasonable thing to do is give some comments, not more. Maybe also mention how the same authors keep coming up, new research subject?

Stakeholders

Is my stakeholder list sufficient as it is? More, less?

Stichting Laka and the document they sent me. Should I now go and spend time on seeing how accurate it all is? Might take a lot of time. DONT HAVE TO REFUTE INFO MYSELF, BUT INCLUDE THIS POINT IN SUMMARY

Greenpeace refused

INQUIRE IF THORIUM IS ON THE AGENDA AT THE TABLE FOR LARGE-SCALE ENERGY PRODUCTION

MINISTERIE VAN EZ CHECK IF CIVIL SERVANTS ARE INDEED NOT AWARE OF THIS

Sources

Much internet info

How to use a source that you use a lot

Report

What about using the I form in my report, this is generally not allowed but is it maybe b/c of the investigative reporting style? Only the case in intro.

**Supervisor meeting 26/05/13**

Attendees: Lucas Pool, Egbert Dommerholt

Ministry of Economic Affair Interview

Received all the information I need

Did extra interview with “Lobby” stakeholder

Interviews so far

Is duration of interviews an issue?
Do I need English translations?

Wordcount

Sourcing

Et. Al issue

About.com?

Can I make a nice lay-out for the report?

How to best describe my research approach

Is my methodology good

**Supervisor meeting 30/05/2013**

Attendees: Conny Dröge-Pott, Lucas Pool

How to best describe my research approach? - Explain why none applies to me, one by one

How do my primary research and data collection method hold up when assessed by the assessment-matrix?

Can I use a nice graphic design/lay-out for (one version of) my report? Or should we stick to black & white, times new roman, etc.? OK, BUT MAKE SURE ALL SUPERVISORS GET THE SAME ONE

Digital version by e-mail? How far done should it be: can it still have my “under construction” signs in it? YES

How should I give my own comments to certain points in the theory? Can it be immediately after in the main text, or should it all be in the conclusion? Comments in different lay-out

Wordcount

If conclusion and methodology are in, can I maybe move much of stakeholders to appendix?

Can I be 10% over? Can I have more words because it is a different kind of report? BETTER TO STAY WITHIN

STAKEHOLDERS IN APPENDIX

Introduction

Prefer some personal statements, is this alright? SEPERATE PERSONAL & REPORT INTRO

Sourcing

I’m using word’s harvard referencing function, it doesn’t do “et al” for example, should I correct this everywhere? How big of a deal is this? NOT AN ISSUE

Does every paragraph need a source, even though the next one is from the same source? USE SOME SIGN INDICATING IT’S FROM THE SAME SOURCE

Do other part like the conclusion needs sources again, even though it has been referenced earlier in the report? REFER TO SECTIONS IN REPORT

When referencing my interviewees as “Dr. Kloosterman said...” do I still need a source at the end with date etc.? Should i add my main articles in the appendix?
H. Project agreement

Company Name: Hanzehogeschool
Address: Zernikeplein 7 / Postbus 30030
Postal code: 9747 AS / 9700 RM Groningen
City: Groningen
Country: Netherlands
Contact Person/Company supervisor: Egbert Dommerholt
Job title: PhD teacher/researcher sustainable finance & threats & opportunities of sustainable business
Telephone number: 06-29454050
E-mail: e.dommerholt@pl.hanze.nl
Homepage: http://www.linkedin.com/profile/view?id=21405529&trk=tab_pro
Short Description of Company:
This is a GPJ for the Hanze IBS lectorate.

International Business School Groningen
Postal Address: P.O. Box 70030, NL-9704 AA Groningen, Netherlands
Visiting address: Zernikeplein 7, Groningen, Netherlands
Co-ordinator: Mrs. C. Dröge
Telephone number: +31 (0)50 595 2318
E-mail: c.m.droge-pott@pl.hanze.nl
Secretary: Ms. L. Penton
Telephone number: +31 (0)50 595 2302
E-mail: a1.penton@pl.hanze.nl

Student Details
Name: Lucas Pool
Student Number: 343236
Address: Noorderstationsstraat 70D
Telephone Number: 0031-643861272
E-mail: l.m.pool@st.hanze.nl

This address is for temporary, internal IBS use only. Please be aware that it does not change your official address in the central Hanzehogeschool administration!!

Agreement
• The company and the International Business School Groningen agree to carry out a project according to the details as specified on the next pages.
• The International Business School will involve the above named student(s) in the project; the
The project process will be supervised by a staff member from the International Business School.

- Students are involved in the project as part of the GPJ module, a compulsory part of their studies. The project and its deliverables will be subject to assessment by IBS staff members.
- The company, the student(s) and IBS Groningen will do everything possible to produce the agreed deliverables on the agreed deadline.
- The company will provide the IBS supervisor with the completed questionnaire regarding the performance of the student.

**Project Details**

**Preliminary Project Title:**

Advantages & disadvantages of thorium fuelled nuclear power when generated in the Liquid Fluoride Thorium Reactor compared to uranium fuelled nuclear power & stakeholders in the decision making process.

**Preliminary Project Description:**

The project will be an investigation into thorium fuelled nuclear power as a potential (sustainable) energy source.

Thorium fuelled nuclear power supposedly is a semi-sustainable (lasts for thousands of years, not indefinitely) energy source that has the potential to solve (part of) the global energy problem. It has many great theoretical advantages compared to traditional uranium fuelled nuclear power that if proven to be true, could take away the misgivings people have about nuclear power. If this type of energy generation would become a reality it will have a massive impact on the (renewable) energy sector and therefore is something that needs to be taken into account. If it proves viable it means a formidable new source of competition, if it does not it is important to exclude the chance of this new source of competition appearing on the market. This knowledge is of value to anyone operating, or looking to operate in the (renewable) energy market, or working on research relating to it.

The project will include a breakdown of how thorium fuelled nuclear energy in the Liquid Fluoride Thorium Reactor (LFTR) works, what its advantages are, what its disadvantages are, which investments (time, money, research) are estimated to be needed for thorium-fuelled energy production to be implemented (as part of its “dosadvantages”), and who the stakeholders in the thorium fuelled nuclear power development process are. Both Dutch and important international stakeholder groups will be identified, but interviews to establish their stance on the subject will mainly be conducted with representatives of Dutch stakeholders.

Secondary research in the form of thorium/LFTR theory will be backed up by primary research in the form of expert- and stakeholder interviews.

The aim is to provide an overview rather than an in-depth exploration of every aspect. The idea is that future theses will dig deeper into aspects that are identified through this research.

**Preliminary Statement of Objective:**

To gain insight into the advantages and disadvantages of thorium fuelled nuclear power when generated in the LFTR, compare them to uranium fuelled nuclear power & identify stakeholders in the decision making process and gauge the opinion of Dutch stakeholder group representatives.

**Detailed Research Questions:**

Which questions and sub questions need to be answered in order to deliver the results?

Research question 1:

What are the advantages and disadvantages of thorium fuelled nuclear power when generated in the LFTR compared to uranium fuelled nuclear power?
Sub- research questions 1:

1.1 What is thorium fuelled nuclear power?
1.2 What are the advantages and disadvantages of LFTR reactor design compared to traditional nuclear reactor design?
1.3 Why is thorium not being used as a fuel today?

Research question 2:

Who are the stakeholders in the development of thorium fuelled nuclear power?

2.1 Who are the stakeholders in the development of thorium fuelled nuclear power in the Netherlands?
2.2 What are these parties’ considerations regarding developing- or not developing thorium fuelled nuclear power?
2.3 Who are the international stakeholders in the development of thorium fuelled nuclear power?
2.4 Which parties are currently involved in actively developing thorium based nuclear power?

Research question 3:

What is the significance of thorium fuelled nuclear power when generated in the Liquid Fluoride Thorium Reactor to (renewable) energy business models, and with that, to the IBS-lectoraat? Are there sufficient grounds to warrant further research into the subject?

Short Research Approach and Strategy:

Deductive, inductive

Experiment, Survey, Case Study, etc.

Multi-method approaches

With regard to the “research onion”, the following applies to this project:

**Philosophy**

The research philosophy best suited to this project is pragmatism. Whichever methods lead to successfully answering the research questions will be the methods to employ. In this case it will be secondary research to develop an as deep an understanding of the subject as possible, which will be put to the test by means of expert interviews.

**Approach**
This research is a combination of deductive and inductive. It is deductive because it starts with theory that is then put to the test through expert interviews, but could lead to inductive research if any truly new information were to be found out.

**Strategy**

This research is descriptive and explorative in nature. It includes a survey of experts in the field and other stakeholders by means of semi-structured interviews.

**Time horizon**

The time horizon for this project can be best described as cross-sectional, as the current position of thorium as a nuclear fuel is being examined.

**Data collection & -analysis**

Caution has to be taken with regard to the data collection and analysis. Reliable sources on thorium-fuelled nuclear power are rare (both written & experts), so the possibility of cross-examination is limited and opportunities that are there must therefore be effectively exploited.

They must also be approached very critically; authors and experts who are positive about the future of thorium fuelled nuclear power might be biased about the subject. (e.g. confirmation bias) They might be so enthusiastic about the prospect of thorium solving the energy problem that they overstate its positive effects and their likeliness, while underestating or even ignoring downsides.

Pessimists on the subject also have to be approached critically. They might be pessimistic on the subject for reasons other than objective reasoning, a belief that this simply sounds too good to be true, or even simply because of the attention that opposing the theory earns them, for example.

Because this project relies on external experts for much of the more complicated theoretical matter, this information is best approach in the most objective way possible. The information will likely lead to a better understanding of the subject, but should not be used to draw definitive conclusions too hastily on a subject of the complexity and scale of the thorium question. It should rather be used as a starting point for future research into the matter that will hopefully yield conclusive answers.

**Brief Methodology:**

How each of the research (sub) questions will be answered

The research that will be conducted to answer the research questions will be as follows:

Secondary research from articles and other written sources will first be conducted to answer as much as possible of the sub-research questions 1.1-1.4.

Sub-research question 1.1 will be answered by giving a breakdown of what the element thorium is, and how it can be used as a nuclear fuel for generating power

Sub research question 1.2 will be answered by explaining how using thorium as a fuel in the LFTR differs from the traditional method of using uranium as a fuel in nuclear reactors, and what its advantages and disadvantages are. This question includes waste, safety, costs, power output, and by-product properties, which were first listed as separate sub-questions of 1.2 but were taken out after being advised to do so by the project supervisor.

Sub research question 1.3 is relevant to the thorium question because even though using thorium as a nuclear fuel has many theoretical benefits, it is not being used as a fuel today due to historical reasons having to do with the development of nuclear power.

The outcomes of this secondary research, and arguments against thorium fuelled nuclear energy in particular, will then be presented to- and discussed with experts in the field to put these counter arguments to the test, and develop a better understanding of the subject.

Interviews are the best primary research method for this project because many kinds of (qualitative) information and opinions have to be collected from different persons.

The method of choice is semi-structured interviews that will be developed with the help of Anna
Berbers, a PhD communication student at the University of Leuven in Belgium with great experience in statistical- and interview-techniques. A draft interview will first be developed to get clear which information needs to be learned, this draft will then be discussed and enhanced with Anna Berbers, and the result will be tried out during test-interviews to see if anything was overlooked. Semi-structured interviews are best suited to obtaining the information needed because some structure is desirable to limit the scope of the matters discussed (focus on arguments against thorium), but new information is also welcome, it can then be decided later which new information to use and which not to. Interviews will be conducted by the researcher and recorded. Transcripts will then be written afterwards, if possible with the help of software like Dragon naturally speaking.

Because nuclear energy/thorium experts are relatively rare, it is very important that the ones that are there agree to an interview. In order to increase the chance of them doing so, official interview invitation letters will be sent which will be signed by a “Lectoraat” representative.

Information from these interviews will be analysed and compared with the theory. The goal is to assess the strength of the arguments against thorium fuelled nuclear energy.

Jan Leen Kloosterman from the TU-Delft and will definitely be approached for an interview, and possibly others like Dr. R.P.C. Schram of the Nuclear Research and consultancy Group, Peter Baeten, director Advanced Nuclear Systems at the Study centre for nuclear energy in Mol, Belgium, and others that may be recommended by before mentioned experts.

Sub-questions 2.1-2.4 will also be answered by a combination of secondary research and interviews.

The stakeholders in the development of thorium fuelled nuclear power will be identified by first creating a preliminary list of stakeholders using reasoning, and adding to it by asking these stakeholders who else they consider stakeholders. Representatives from these groups will be interviewed to get their opinion and stance on the matter of developing thorium/LFTR energy production.

These stakeholder representatives are less hard to find than nuclear/thorium experts and will be contacted later, most likely using less formal channels.

Stakeholder groups identified thus far are: scientists, politicians, companies, lobby-groups, and press.

Research question 3 will be answered by combining all the information gleaned in this research. Its aim is to make recommendations about the relevance of thorium based nuclear power to the IBS-lectoraat, and whether this is a subject to pursue further in future research or not.

**Secondary sources to be used:**

**Articles/reports**


National Nuclear Laboratory (UK) (2012) “Comparison of thorium and uranium fuel cycles, A report prepared for and on behalf of Department of Energy and Climate Change”


**Online**

Deliverables, Language:

What will be the tangible results of the project (report, presentation, database, etc), and in which language?

The project will produce a report, a presentation, and a graphic representation of the report’s outcomes in the form of an info graph. All three deliverables will be in English.

Constraints and Expected Difficulties:

What can be foreseen to jeopardise the smooth running of the project?
This GPJ is structured differently from traditional IBMS GPJ’s, and it is therefore up to the writer to create a suitable framework that adheres to IBMS criteria.

There are not many experts in the field of thorium fuelled nuclear energy. A major constraint therefore is this project’s ability to secure interviews with those experts.

**Planning**

**Deadlines:**

(n.b! IBS Project Report cannot be postponed without approval of the coordinator of IBGJ(2½S))

IBS Project report: 14 June 2013

**Communication**

Communication between project team, students, company, IBS supervisor

**Details:** Meeting in person will be primarily between the student and the company (IBS lectorate) supervisor. Meetings with both supervisors will be scheduled when necessary.

**Confidentiality**

The report will not be treated confidentially, unless specified otherwise.

Statement of Confidentiality

If the front page of each copy of the report is labelled ‘CONFIDENTIAL’ or ‘VERTRAULICH’, the report will only be made available to the Graduation Project Co-ordinator and the assessors for assessment purposes only. The report will not be given to any third party, including other staff, students, library etc.

The report cannot participate in any award contest.

The above statement of confidentiality Does not apply

Moreover, the student and the International Business School agree that no information regarding business processes will be passed on to third parties during and after the termination of the contract. This applies specifically for client and dealer lists, turnover data, as well as other financial and economical figures relating to the company or its clients, if not specifically allowed.

Facts and figures relating to the core company information as mentioned above will be modified so that confidentiality can be guaranteed. These issues will and have to be discussed with, clarified and approved by the managing partner of the company.