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Technical and economic study on the concept of a twin HTR unit operating in nuclear cogeneration run

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Abstract:

The cogeneration is daily practice in the conventional power plant technology. It is very likely that the nuclear cogeneration will spread worldwide in the near future and enters into operation in the ranges of intermediate and high temperature and heat demands. Intensive research is underway in order to make the nuclear cogeneration a reliable and viable option with the use of (Very) High Temperature Reactor ((V)HTR) concept. More than 1000°C temperature of ~~the~~ Helium coolant at the outlet of reactor pressure vessel can be achieved applying the HTR concept. This very high temperature enables that the HTR provides process heat for technologies characterized by high temperature demand such as hydrogen production and carbon gasification. SC obj ? This paper presents a coupled heat schema – economic study on the nuclear cogeneration run of an imagined industrial site which is supplied by electricity and process heat produced by a twin unit HTR nuclear power plant. SC The heat schema modelling was performed by the application of Cycle-Tempo software. Three process heat output line~~s~~ were modelled to provide process steam for technologies with low, intermediate and high temperature demands. The optimal size (thermal power) of the HTR units was specified due to the results of the heat schema analysis. The economic part of the study is based on net present value calculation which provided insight of the complex relation system between the size of the units and different economic parameters (e.g. price of different energy types, inflation, capital and other costs, etc.) in order to specify the return rate and payback time.

Keywords: coupled heat schema – economic analysis, (Very) High Temperature Reactor ((V)HTR), NC2I-R project, Cycle-Tempo, net present value.

1. Introduction

Nowadays the application of cogeneration is widespread in ~~the~~ conventional electricity production industry. The exploitation of waste heat and the efficiency increasing of complex systems are ~~in~~ the focus of cogeneration in case of conventional power plants (András Urbán,Tamás Velenyák & Attila Kiss 2016). The idea of nuclear cogeneration is neither new nor unprecedented. But the current applications mostly limited to supplying technologies with low temperature and heat demands (residential or process heat). Its main reason is the limited temperature of the currently available nuclear heat sources which mostly ~~belongs to the class of the~~ widespread ~~pressurized water~~ reactor (PWR) (András Urbán,Tamás Velenyák & Attila Kiss 2016), (Iván Gács, Botond Czinkózky, Bihari Péter 2008). The collaborating research community and the nuclear industry of the European Union (EU) play an important role in the research and development of nuclear cogeneration. The dominant direction of this collaboration is the research on nuclear cogeneration with generation IV reactors. As a good example, the series of European efforts on the research and development of HTR can be mentioned (Anon 2016b).

The HTR is a generation IV reactor concept which is under development worldwide (Anon 2016a). It differs in its features from the generation III and III+ class of nuclear reactors which are currently being built (Gyula Csom 2004). The coolant of the HTR is helium instead of the widely used light water while its moderator is graphite. The importance of using helium gas as coolant is that the core outlet temperature can reach 700 or 1000°C in case of helium while this value is around 300°C in case of applying light water (Attila Aszódi 2009), (O.Baudrand & V.Noel 2011). Except of some exotic applications, the nuclear cogeneration has been realized only for residential heating purpose due to the available temperature levels at the operating nuclear power plants (Vincent Chauvet 2013).

The Sustainable Nuclear Energy Technology Platform (SNETP) determines the main direction of ongoing research efforts in the EU (Anon 2016b). The Platform has three pillars. One of them is the Nuclear Cogeneration Industrial Initiative (NC2I). The so-called NC2I-R project (which was funded by the EU as a FP7 project) has been done in the framework of NC2I pillar between October 2013 and September 2015. Its project consortium consisted of more than twenty partners (research organizations, universities, utilities, private companies, etc.). The started and continued work in the NC2I-R project will be elaborated further in the frame of Gemini Initiative (The GEMINI Initiative 2014) and future EU projects.

This ~~paper presents the~~ coupled heat schema – economic study performed at the BME NTI on the nuclear cogeneration run of an imagined industrial site which is supplied with aim of the paper?

electricity and process heat produced by a twin unit HTR nuclear power plant. The heat schema modelling was performed by the application of Cycle-Tempo software (Asimptote 2017). Three process heat output lines were modelled to provide process steam for technologies with low, intermediate and high temperature demands. The optimal size (thermal power) of the HTR units was specified due to the results of the heat schema analysis. The economic part of the study is based on net present value calculation which provided insight of the complex relation system between the size of the units and different economic parameters (e.g. price of different energy types, inflation, capital and other costs, etc.) in order to specify the return rate and payback time.

2. Objects and applied methods

As it was previously mentioned, the nuclear cogeneration is used mostly for residential heating purpose (though e.g. in Switzerland it was used to provide process heat for paper manufacturing) due to currently available temperature levels. However only 25% of the industrial process heat demand belongs to the low temperature range (100-250°C), further 35% can be categorized into the intermediate range (250-550°C) (Vincent Chauvet 2013). The heat demand of these two ranges can be satisfied by conventional power plants or new design of gas cooled nuclear reactors which have higher temperature parameters. To provide process heat for the remaining 40% of industrial process heat demand which mean high temperature range (550-1200°C, e.g. iron and steel production) the currently used widespread conventional and nuclear power plants are incompetent. The low and intermediate temperature ranges need about 800 TWh_{th} energy annually. The energy market is partially well established for these two ranges. The application of new nuclear cogeneration technology (like HTR) should be taken into consideration in case of necessary substitution or reconstruction of the present capacity (Vincent Chauvet 2013). But no doubt that wide international unity is needed for the full-scale deployment of nuclear cogeneration. pe

aim The strategic aim of the NC2I-R project was to contribute to the preparation for a demonstration of the nuclear cogeneration by a demo HTR operating in cogeneration run (Khamis 2013). To reach this aim there was a need for continuous and efficient coordination on the contributions provided by more than twenty project partners (András Urbán, ~~Tamás Velenyák~~ & Attila Kiss 2016), (Khamis ~~2013), (The~~ GEMINI Initiative 2014). aim The further aims of the project were to increase the attractiveness of the HTR technology among the potential investors and the acceptance among potential industrial end-users and society. The public results of previous EU project (called "Europairs") which was performed in the framework of the NC2I pillar of SNETP as well was used in the NC2I-R project as basis knowledge. The possible use of HTR for providing industrial

"aims 1-3" are aims of this EU project, not of this paper!

process heat was investigated in the Europairs project in order to reduce the consumption of fossil fuels and thus the emission of greenhouse gases. Another aims of this project were to investigate the possibility of hydrogen and synthetic fuel production by HTR and preparation for demo building for HTR. These above mentioned aims are under research outside Europe as well, e.g. in China (VHTR-10 test reactor), in the USA (NGNP project), in Japan (HTTR test reactor) or in South-Korea (O.Baudrand & V.Noel 2011).

The aim of the NGNP (The Next Generation Nuclear Plant) industrial alliance in the USA is to decrease the energy dependence of the USA on fossil energy sources and increase the security of supply due to the utilization of high temperature gas cooled reactors (HTGR) in cogeneration run. Another notable development in this field is the GEMINI Initiation which aims to a simple, transparent, accountable and strong agreement between the US and EU private sector companies to work with their governments under an international agreement framework to carry out the design and regulatory work for the first commercial HTGR (The GEMINI Initiative 2014).

3. Developing concept

The basic aim during the design of an entirely new concept was to create such an interconnected system that allows supplying plurality of end-users with particularly high heat and electricity demand. This should be carried out with a continuous, CO_2 emission-free and reliable energy source. For this purpose It ~~was~~ was selected a nuclear power plant as the basic source of heat which is a twin-block design VHTR ~~in our model~~. The leaving heat of helium from the reactor vessel will be passed in steam generators. The working fluid or coolant is heated up to 500°C. The steam generators are producing on a common main steam branch where almost the whole available working fluid is fed into high pressure turbine. The design of system allows that the steam can be taken in front of the high pressure turbine, if the process heat demands make this necessary. Heat exchangers ~~which~~ supply industrial end-users are heated with suitable quantity and quality of steam by tapping points of turbine and initial or intermediate steam detract (Vincent Chauvet 2013). The basic circuit was realized at two different pressure levels in the end-user side, shown as Fig.1. But later, it is also possible to be increased the number and quality of demand levels. The leaving heat transfer medium from the surface of heat exchanger in the tertiary loop is delivered meet the need of thermal energy to the site where separate heat utilization take place (Anon 2016b). In ~~the~~ further section of secondary circuit, the steam is passing through the low-pressure turbine and finally it goes to the condenser. As the condensation is completed, the following part of the cycle is a traditional feed water preheater row which fed by turbine tapping. From here, the working fluid is introduced again to the steam generators. To demonstrate this idea, Cycle-Tempo model was built

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which has been developed according to the wiring diagram, shown as Fig. 1. The presented parameters here are only the expectations of calculation.

4. Safety consideration

WAS

The nuclear safety is ~~already~~ a complex topic in case of nuclear power plants operating nowadays. The fourth generation VHTRs ~~are~~ having a basically different construction, and be used materials with special parameters, so in this case, the conditions of inherent safety should be built in other basis. SC / PE

The applied moderator in the construction is graphite, instead of the nowadays preferred light or heavy water. The graphite is a burnable material unlike the previous ones, but the lack of oxygen in the primary circuit prevents its flame up. Furthermore, it is important to emphasise that in the primary circuit, there won't be any contact between the graphite and the helium. The whole primary security technology system should be built on an absolutely new basis.

Besides the previously discussed topic, a new, not yet examined viewpoint should be kept under review. With the given connection which is not only located in the proximity of an industrial site – which can be handled as an independent security problem – but also operates in tight cooperation, and they have mutual impact on each other's activities. Consequently the safety considerations should be divided into two groups, namely how the industrial site influences the operation of the power plant and vice versa (NEA/NDC 2013).

Keeping the nuclear safety in the first eye, the additional risk of the end-user should be taken foremost under consideration for the power plant. In that case, the end-users are mostly chemical sites, supplied with process steam and electricity produced in HTR units. The source of danger mostly depends on the structure of the chemical sites, and furthermore ~~the~~ products used and produced. In the vast majority of cases the source of problem is, that the storage some material loses its integrity temporary or in long term. The released chemical substances could cause fire or burning in one hand. On the other hand, in the case of a potential explosion, the pressure peak, the heat effects and the dispersal of debris should be taken under consideration separately (NEA/NDC 2013). PE SC

PE In ~~the~~ terms of potential impacts of the industrial site on the nuclear power plants, the direct and indirect impacts should be distinguished. The direct events are those, which affect the main equipment and the coolant system. The indirect events are such malfunctions, which cause a transient in the intermediate heat exchanger or in the steam generator, or influence any other additional systems. On the other hand, those events also PE belong to this category when due to the effect of a toxical release, the operating staff cannot perform their work.

The fact, that the energy for the industrial site is supplied by a nuclear power plant must not influence its safety, continuous operation and the quality of final products. Consequently, in the terms of normal operation and design basis accidents, the effects of an event should be kept in the area of the nuclear power plant.

The potential effects caused by a power supply shutdown mostly depend on the processes used by the end-users. Consequently, over the damage to property – workpieces become useless during work, equipment destroyed – some other problems can occur– fire, explosion, toxical release. In nuclear power plants operating with HTR units, the most common issue could be the tritium contamination. The evasion of tritium must be kept under a limit, in order to reduce its amount in the end product and to minimize the dose of workers involved manufacturing process. During the preparation of emergency plans, both parties involved should set up new elements, because of the different safety principles and rules. To compliance this objection, it will be a major challenge for the experts (O.Baudrand & V.Noel 2011).

5. End-user demands

To each potential industrial and residential end-users demand are served safely, it will be necessary to define different demand levels of end-user. From the presented system perspective, the issued electricity to the network is a secondary product. The primary objective of design is to supply the industrial customers with large and constant heat demands. The output of heat circuit fitting to the system plays a key role in the released amount of electricity. Since, it is decided to which the tapping points are, where the tapping is carried out for serving the heat demands of industrial customers. According to the basic assumption should be made a difference between two levels of demand. These cycles can be characterized as high and low thermodynamic parameters.

Higher heat demands are provided by the high-pressure turbine while lower demands are ensured by tapping points of the middle- and low-pressure turbine. The direction of the further development may be the concretisation, separation and optimization of demand levels. According to the formation of model, the return flows of the heat circuits can be applied for preheating tasks. It can be done at the side of power plant and in the industrial facility, as necessary. Because of the simplifications and uncertainties in the model are not worth to draw definitive conclusions. Since, it being necessary a high-level cooperation between nuclear facilities and industrial end-user group. But it seems clear according to the present state of projects that the industrial and residential heat demands jointly can be solved by the nuclear side.

6. The analysis methodology

The applied considerations for both the heat scheme and economic analysis are going to be presented in the following two separated sub-chapters.

6.1. Considerations of technical analysis

During the creation of the general model was considered all of the studies which was undertaken within the framework of Europairs project (NEA/NDC 2013). According to the analysis of the project an appropriate venue for demonstration related examination would be Chemelot Site which is a complex chemical industry, located at the Netherlands. The site is approximately 800 hectares which involves 50 different chemical processing units with variety of heat demands. Many companies interests can be found here, including DSM, SABIC and DEXplasomers (NEA/NDC 2013). Currently, the combined demand of heating steam and electricity are served by natural gas-based cogeneration. However, the rapid depletion process of fossil fuels and associated with the incremental costs justified the study of different concepts in order to sustainable energy management.

The envisioned system for industrial site of Chemelot gave guidance during the modelling process. Meanwhile, same type of nuclear power plants which already in operation was taken into account. Based on the envisioned wiring diagram in the Fig. 1 where can be found the specific parameters too, the steam supply of sites is provided. Later, basis of these considerations the model was constructed by Cycle-Tempo. The model was made for use of a global nature, since the basic model provides an opportunity for calculations with other parameters too. Thus the test cases ~~were~~ became comparable under the same boundary conditions. The analysis was carried out based on the principle of ceteris paribus. It has been analysis concerning the system what the impact whether a single parameter of changes is in case of the other values remain unchanged. Within the framework of this study, constructs with variety of reactor performance were compared through an optimization process.

6.2. Considerations of economic analysis

The economical calculations are made with discount cash flow formulas, which can be seen in Eq. 1.

$$\boldsymbol{NPV = \sum_{n=1}^{N} \frac{E(F_n)}{(1+r_{alt,nom})^n}} \qquad (1)$$

Where

n	the number of years from the beginning of the construction,
N	the total number of years,
$E\,(F_n)$	predicted yearly cash flows,

$r_{alt,nom}$ the nominal interest rate.

The return on invested capital was examined as a free market project, so we do not take into account the capital structure. The values used in our calculations can be classified in two major groups: general economic parameters, values in connection with the construction and the price of process heat and electricity.

During our calculations, the nominal capital cost was 8%, consisting of the 2% inflation and 6% real term capital cost. In the power engineering section, the 6% real term capital cost is a common value. Nowadays the inflation rates are mainly lower, but in a 50-year long perspective it could be an average value.

In connection with the construction cost, our calculations were based on an AREVA study. (Brinkmann et al. 2014). This document deals with a 250 MW_{th} twin HTR unit technological and economical background. The main parameters can be seen in the Table 1:

Some different reactor powers were investigated. For these powers detailed calculations were not provided, so the emerging cost was calculated with conservative approach. The 2×200 MW_{th} power with the 85% of the basis value, the 2×300 MW_{th} power with the 115% of the basis value, 2×400 MW_{th} power with the 145% of the basis value, 2×500 MW_{th} power with the 175% of the basis value, 2×750 MW_{th} power with the 205% of the basis value. The yearly growth of the O&M costs is the same, as the inflation rate, because it mostly depends on the price of processing and human work, then the raw material, so its price increase will be similar to the inflation rate.

Forecasting the energy prices is a difficult task even in short term, but in such a long term there are a lot of different viewpoints in this area. In our calculations the prices were utilized from an EON study preformed in a similar topic. This document reports 0.08 EUR/kWh process steam price, and 0.1 EUR/kWh electricity price. During the whole project the real term annual price increase of these products is assumed 2%/year. It is valued by the projected industrial development and the increase of energy needs.

7. The heat schema model

The ideas have been implemented in the form of model in Cycle-Tempo software (TU Delft 2011). Thus, based on the calculations which were made by the software, the feasibility of nuclear based process heat supply was investigated. The global nature of model ensured that the various constructions were compared under the same boundary conditions. Based on the results which derived from the Cycle-Tempo, the generation IV of nuclear facilities' reactor performances were critically evaluated.

Summary of the main results derived from the application of Cycle-Tempo are shown in Table 2. It is important to emphasize that the presented parameters in Fig. 1 are only defined by the imagined level of demands therefore the results of calculations can be found in Table 2. During the modelling process the number of heat circuit have been expanded, thus industrial end users with intermediate heat demands can be served too.

7.1. Modelling of the primary circuit

According to Fig. 2 the design of the primary side is modelled. The vapour mass flow of nominal operating conditions is 480 kg/s in the main branch which evenly divided into two closed loops. The possibility of distribution of load have been provid~~ing~~ed in order to the system behave elastically when the demands are different from the nominal operating conditions.

In case of one closed-loop the heat capacity is permanently 500 MW_{th} which was modelled by two separate heat sources. According to the construction of HTR the coolant is helium which has a relatively large heat capacity and even more chemically inert.

7.2. Modelling of the thermal circuits

It is necessary to make a general overview about the applied and modelled turbine system before the heat circuits will be presented. The turbine is divided into two terms among which reheating provides the condition of steam (Siemens 2013). The schematic view of the design can be seen in Fig. 3.

Examining the whole system, the amount of electricity from the generator side is distinguished. This is maximized in order to the profit. However, this is achieved depending on the supply of sufficient quantity and quality of process heat which can be provided for the industrial end-users. According to the model, the realization of heat circuits is solved which shown in Fig. 4. Designed circuits which fitted to the system play a major role in the amount of released electricity. Since crucial question is which stage will be constructed as tapping point to serve the heat demands of industrial consumers.

According to the standard design two circuits were structured which divided into high and low thermodynamic parameters of heat cycles. The requirements of high temperature (HT) are provided by the high pressure turbine for industrial consumers, meanwhile the lower one (LT) is supported by the medium-low pressure turbine. Since the two different circuits are served such groups of consumers whose demands ~~are~~ differ greatly. Therefore, during the modelling process a third circuit was constructed which can serve middle demands (MT). Thus the losses are reduced during the heat exchange process. Furthermore, more and separated groups of industrial with different heat demands can also be served. The parameters of heating steam are presented in Table 3.

Due to the design of model the return flow may be able to serve preheating tasks for industrial processes too. However, it must be ensured that the discharged quantity necessarily be replaced due to the principle of constant flow rate of system.

8. Results

The results of the coupled heat scheme and economic analyses are presented separately in the following. But the authors summarize the lessons learnt from the coupled analysis in the conclusion.

8.1. Results of the technical analysis

Based on the results which are obtained from the model optimum test was conducted for the reactor thermal performance. This was carried out by the ratio of heat and electricity power (T/E) in each individual test case. The carrying capacity of industry was considered. Therefore, the maximum value of released heat was limited. The efficiency of the nuclear-based cogeneration can be characterized by T/E ratio which was calculated based on the Eq. 2.

$$T/_E = \frac{Q_{released}}{P_{max} - P_{released}} \quad \textbf{(2)}$$

According to the Eq. 2 concluded that, the defined efficiency ratio derived from the ratio of released heat and the difference between the maximum and released electricity. With this can be characterized that, how large amount of electricity sacrificed is to serve heat demands of industrial end-users.

The optimum searching results can be seen in Fig. 5. Based on the figure the optimum of reactor performance is placed between the 2x400 and 2x500 MW_{th} reactor which can be seen by polynomial fit. Between the two reactor performances the limit is too tight to make a clear conclusion about the best design. This uncertainty of polynomial fitting was not permitted. However, the best range is clearly visible in Fig. 5.

8.2. Results of the economic analysis

As we mentioned previously, the economic calculations were made with NPV method, where the yearly cash flows were calculated as the yearly incomes minus the yearly outcomes. The production is adjusted to the heat demands, because the electricity needs can be covered from the grid. The annual availability rate is 7446 hours, which is 85% utilization. This is a normal value in the terms of nuclear power plants.

The investments cost can be depreciated in the first 15 years. The taxes were calculated as a concentrated value after the yearly result, rate of which is 20%. For calculating the NPV the net incomes were summarized. The high uncertainty of the economic parameters makes it necessary to prepare a sensitivity analysis for our calculations. In that term the predictions were made not only with discrete values, but also extensive analysis was computed. First a scenario analysis was prepared with different powers and energy prices. Then for the economically optimistic construction, a sensitivity analysis was prepared revealing which parameters pose the highest risk for the revenue of the project.

The scenario analysis can be seen in the Fig. 6, and was calculated with six different rector power (Fig. 5) and four different energy prices. The heat and electricity power ratio was not changed, because these are substitutable products.

The results meet the expectations, as the NPV values are getting higher with greater differences towards the higher powers. The greater variance of course results higher risk. Accordingly, the 2×400 and 2×500 MW_{th} cases seem to be the best from an investment point of view, with an account of the profit-risk combination. Moreover, in these cases positive NPV can be earned in the widest range of energy prices. In the cases of lower energy prices, the curve seems billowy. The fluctuation is due to the fact that the higher investment costs are not covered by the greater amount of produced energy.

The sensitivity analysis for the 2×500 MW_{th} case can be seen in Fig 7. The diagram reveals which parameters pose the highest risk for the revenue of the project. The examined parameters certainly influence other values as well, but the calculations were made with the ceteris paribus principle, so only one parameter was changed at once.

The NPV is mostly influenced by the availability rate, the cost of capital and the heat and electricity prices. Such a big alteration in the cost of capital is almost inconceivable, but it certainly would influence other parameters as well. The availability rate was investigated in a short range, because its higher alteration would not be an economical problem, rather an energy supply and operating problem.

The price of process steam has a greater influence on the NPV than the price of electricity, thanks to its higher production value. The operating time and the decommissioning cost weakly and the construction cost strongly affects the results. It is due to the fact the costs appearing later have smaller influence on the NPV in the long term run.

9. Conclusions

The realized cogeneration concept with generation IV nuclear power plant could play a major role in decreasing pollutant emissions and greenhouse gases in the future. Whereas, in the framework of the imagined design, large industrial demand could be served with combined continuous heat and electricity.

Within the study, the optimal reactor power of examined site has been specified. It is between the range of 2×400 and 2×500 MW_{th}. However, the technical analysis should always be accompanied by an economic analysis which can be taken into account the financial frames and recoveries. This will help take a position on the feasibility of construction.

The economic calculation of the presented case study revealed that, the higher performance of the unit is selected, the higher dispersion of the net present values (which resulting higher risk). It can be concluded, the best cases are 2×400 and 2×500 MW_{th} by the point of investors because these performance levels can be achieved the highest pairing of profit-risk. Furthermore, in the widest range of energy prices can be realized a positive net present value.

Based on the sensitivity analysis, the most significant effects on the net present value are the annual availability rate, cost of capital, process heat and electricity price.

Acknowledgement

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List of figures and tables

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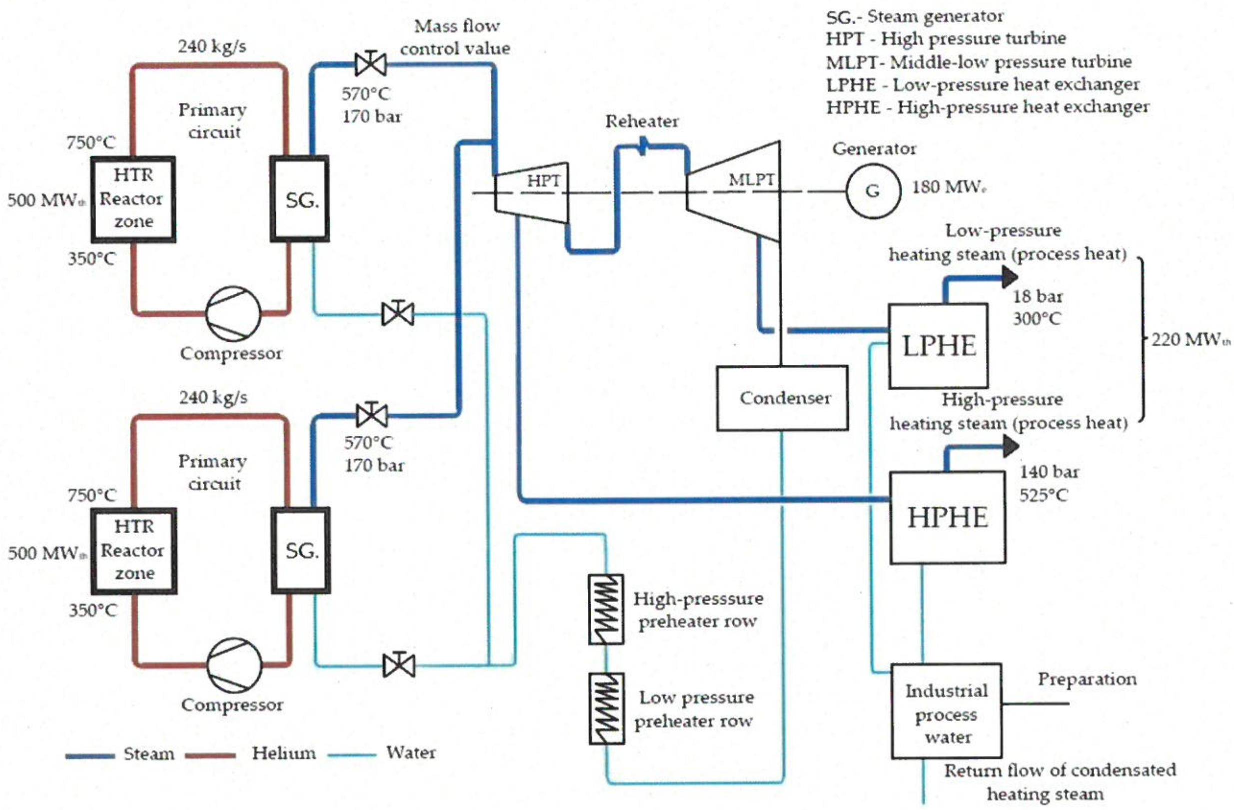

Figure 1 *Imagined connection diagram of steam supply for Chemelot Site*

Table 1 *The main costs*

Item	Value	Unit
HTR construction cost	930.8	million EUR
O&M cost	23.4	million EUR/year
Decommissioning cost	115.0	million EUR
Fuel cost	27.1	million EUR/year

Table 2 *The main parameters*

Notation	Denomination	Value
p_1	Fresh steam pressure	169 bar
T_1	Fresh steam temperature	570°C
p_{RE}	Reheating pressure	70 bar
T_2	Reheated steam temperature	555°C
p_{cond}	Condenser pressure	0.04 bar
P	Released electricity	227 MW_e
Q_1	1. Thermal power	150 MW_{th}
Q_2	2. Thermal power	100 MW_{th}
Q_3	3. Thermal power	50 MW_{th}

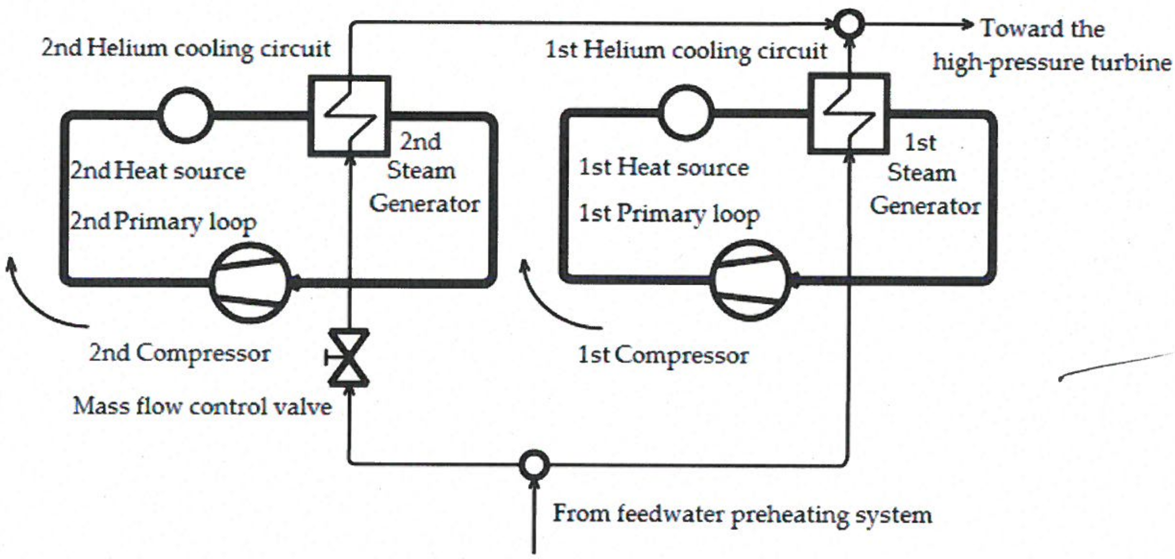

Figure 2 *The design of duplicated primary loop circuit*

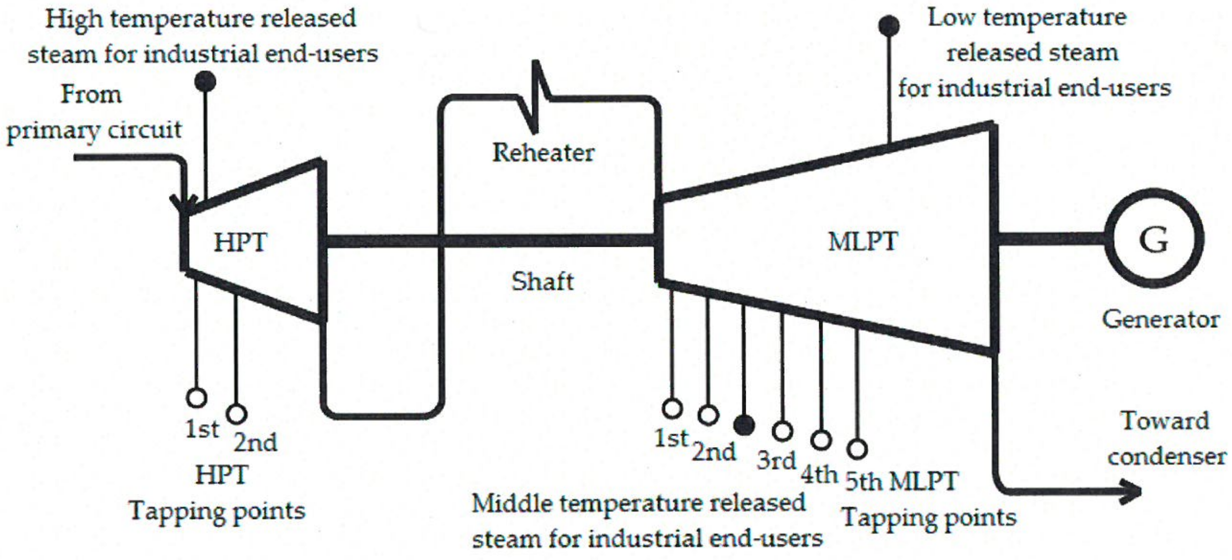

Figure 3 *The design of the turbine system* ?

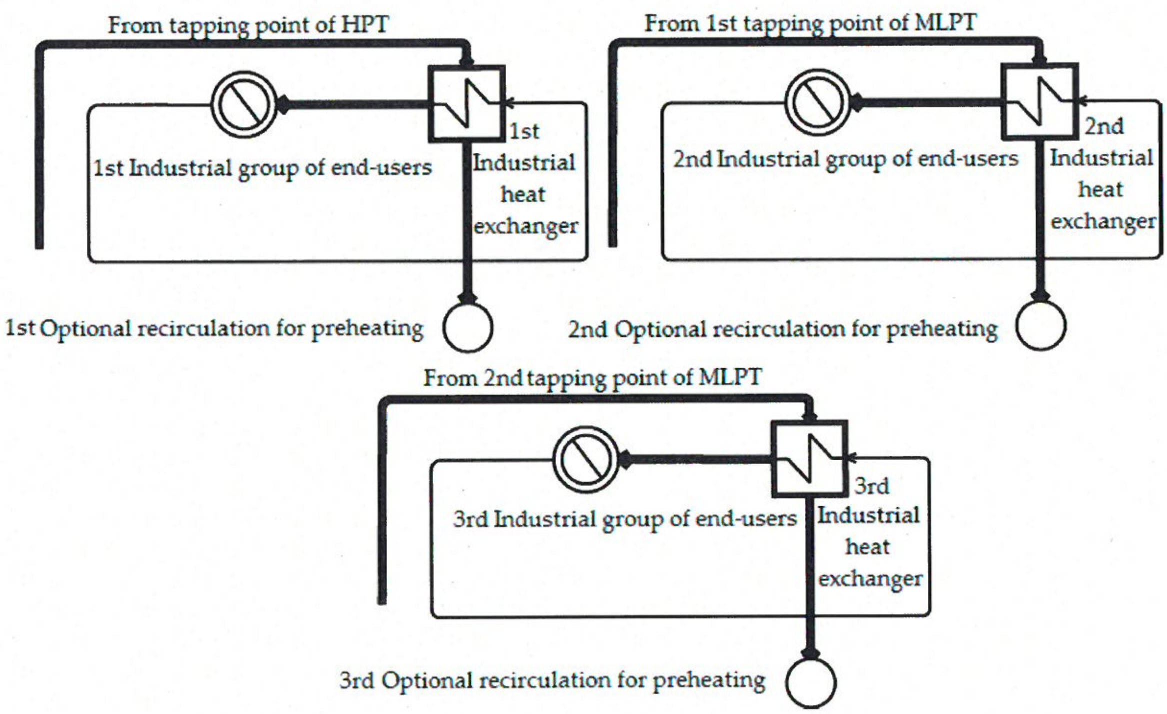

Figure 4 *The sketch of heat loops* ?

Table 3 The typical parameters of heat circuits

Notation	Value
p_{HT}	12 bar
T_{HT}	540°C
p_{MT}	3.5 bar
T_{MT}	460°C
P_{LT}	1.8 bar
T_{LT}	340°C

is this a good order for the polynomial?

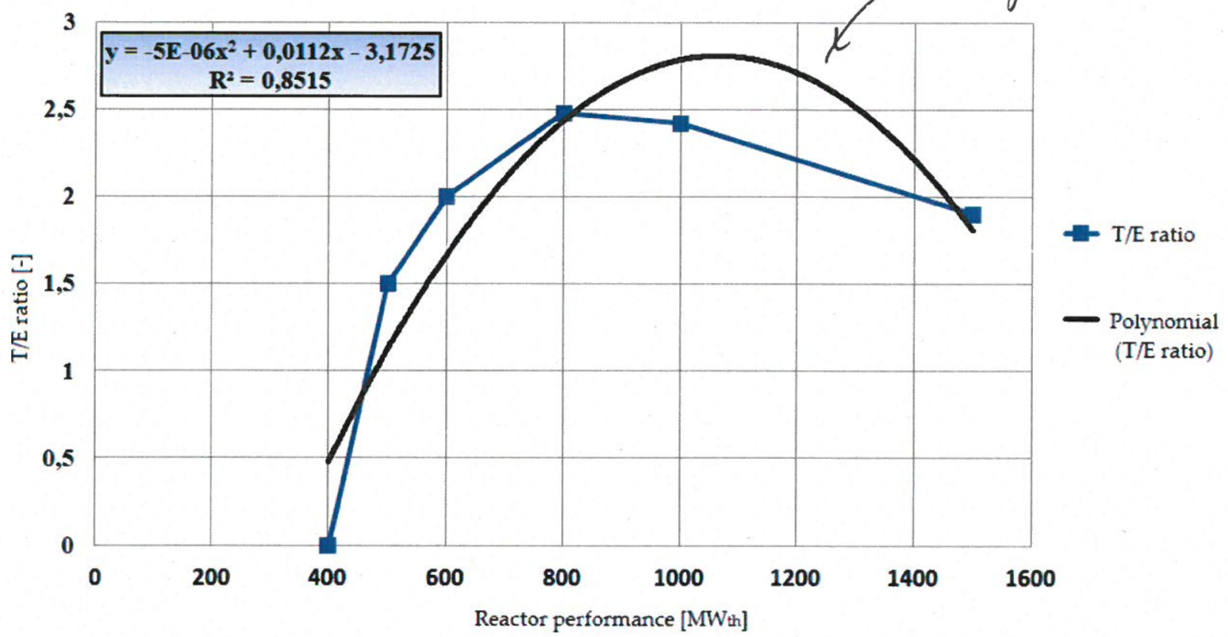

Figure 5 *The optimum reactor performance defined by the efficiency ratios (T/E)*

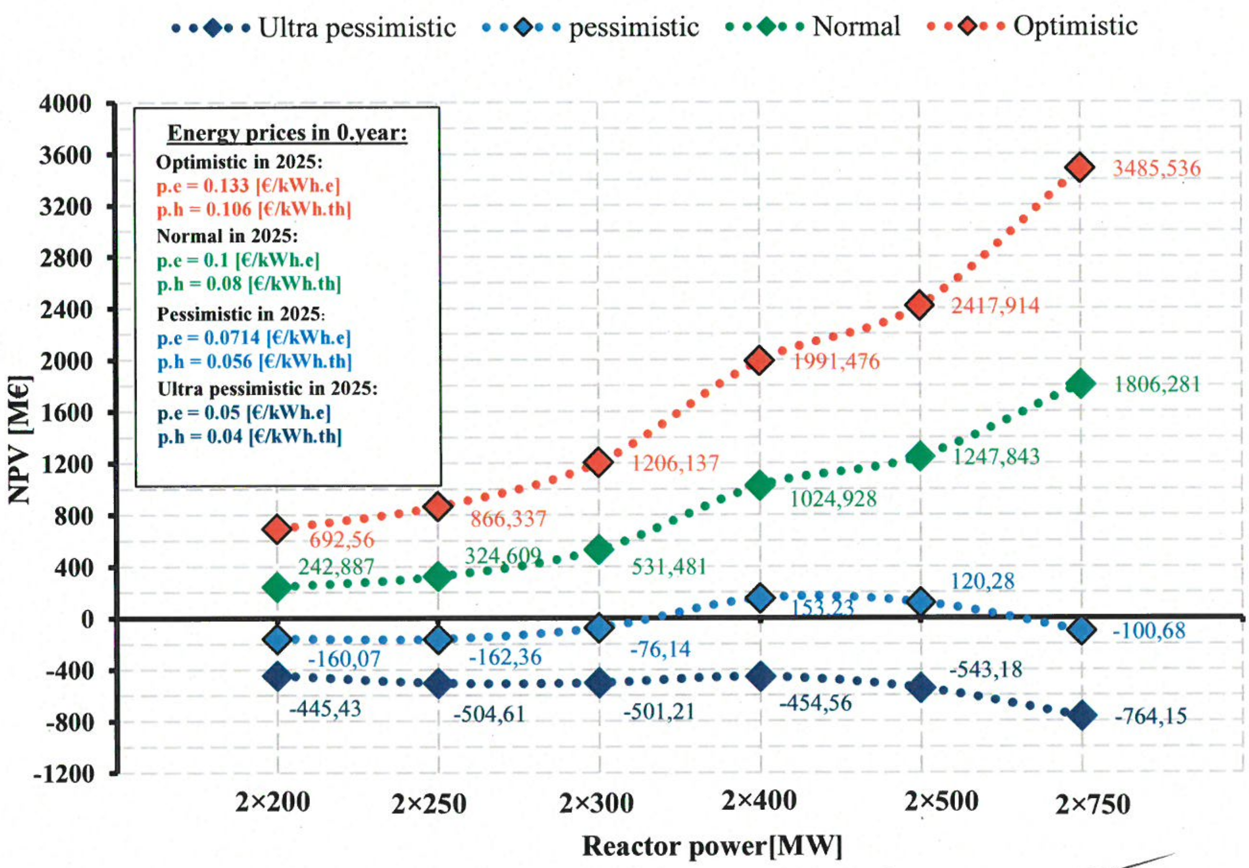

Figure 6 *The result of the scenario analysis*

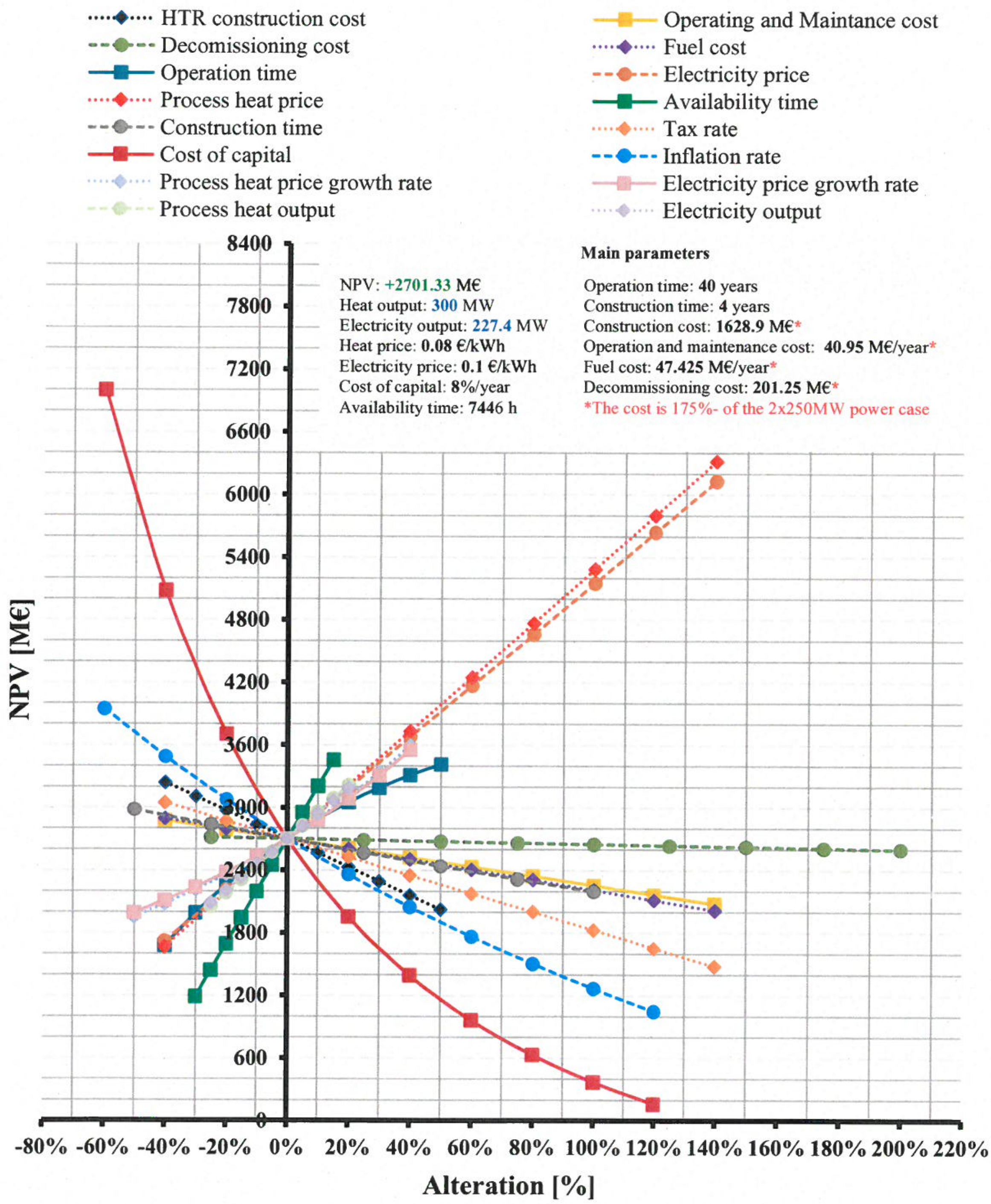

Figure 7 *Sensitivity analysis for the 2×500 MW$_{th}$ HTR, in the case of Chemelot Site*

*Abstract

Technical and economic study on the concept of a twin HTR unit operating in nuclear cogeneration run

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Abstract:

The cogeneration is daily practice in the conventional power plant technology. It is very likely that the nuclear cogeneration will spread worldwide in the near future and enters into operation in the ranges of intermediate and high temperature and heat demands. Intensive research is underway in order to make the nuclear cogeneration a reliable and viable option with the use of (Very) High Temperature Reactor ((V)HTR) concept. More than 1000°C temperature of the Helium coolant at the outlet of reactor pressure vessel can be achieved applying the HTR concept. This very high temperature enables that the HTR provides process heat for technologies characterized by high temperature demand such as hydrogen production and carbon gasification. This paper presents a coupled heat schema – economic study on the nuclear cogeneration run of an imagined industrial site which is supplied by electricity and process heat produced by a twin unit HTR nuclear power plant. The heat schema modelling was performed by the application of Cycle-Tempo software. Three process heat output line, were modelled to provide process steam for technologies with low, intermediate and high temperature demands. The optimal size (thermal power) of the HTR units was specified due to the results of the heat schema analysis. The economic part of the study is based on net present value calculation which provided insight of the complex relation system between the size of the units and different economic parameters (e.g. price of different energy types, inflation, capital and other costs, etc.) in order to specify the return rate and payback time.

Keywords: coupled heat schema – economic analysis, (Very) High Temperature Reactor ((V)HTR), NC2I-R project, Cycle-Tempo, net present value.

PE: Poor English
SC: Sentence(s) is/are very confusing.