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A SIMPLE TOOL FOR DESIGNING AND ASSESSING THERMAL GROUNDWATER UTILIZATION

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ABSTRACT

The simulation of fluid flow and heat transport in a reservoir has been an essential part in the planning process for geothermal projects for the past 30 years. Various sophisticated simulator codes are available today, capable of handling almost any hydrogeological setting and project complexities possible. However, these codes are valuable only in the hands of qualified modelers and the cost and effort required for a model may be inappropriate for the scale of some projects.

We have developed a simple tool with various applications for the thermal utilization of groundwater (for heating and/or cooling). The tool may be used in a preliminary planning phase to study the hydraulic and thermal processes in the aquifer, and to optimize the design. It also serves well for the management of projects competing for one aquifer. All considerations are based on the local conditions.

Our tool, which we refer to as a groundwater energy designer, enables consultants, drillers, technical engineers and licensing officers

- to determine the necessary flow rates for a desired heat (or cold) output,
- to specify the characteristics of the wells in order to meet this demand with the given geohydraulic conditions on site,
- to simulate the flow and heat transport in the aquifer (and surrounding layers) based on a set of lumped parameters and the local hydraulic flow field and

to visualize the effects of the utilization for user-defined locations, flow rates, and production and reinjection scenarios.

The innovative part of the tool is a simulator which selects the appropriate model domain, boundary conditions and discretization without any intervention of the user being necessary. The computing time is extremely short and the results are presented right away as isolines of temperature and drawdown for the simulated case.

Our groundwater energy designer has been verified with a set of single-phase TOUGH2 calculations.

This paper presents the advantages and limitations for the application of our tool, and potential project objectives attainable with it.

MOTIVATION

The planning phase for facilities with groundwater utilization, either for heating or for cooling purposes, with reinjection of thermally altered water, is characterized by three fundamental questions: Is there a sufficient water resource at the local site? Is the property extensive enough for reinjection without a breakthrough into the pumping well? Could neighbours be affected by the reinjected water? In addition to the last question also the extent of thermal or hydraulic impact on existing sites or drinking water supply has to be assessed.

To answer these questions predictions based on geothermal simulations are necessary, but for small or medium size units the involved effort is often inappropriately large and time consuming. We have developed a dedicated software package - *Groundwater Energy Designer* (GED) – which is designed to enable consultants, drillers, technical engineers and licensing authorities to address considerations of position for pumping and reinjection of thermally used water. By allowing the user to test various potential configurations based on demand and hydrogeological characteristics, it provides an effective iterative optimization tool.

ANALYSIS OF DEMAND AND DIMENSIONING OF EQUIPMENT

Based on an initial analysis of the demand for heating or cooling, a first step aims to determine the required flow rates. Two specific flow rates are essential for the site dimensioning:

- the annual maximum flow rate for the dimensioning of the wells (number and installation)
- the annual averaged flow and temperature change for the assessment of the impact of reinjection and to determine the necessary distance between pumping and reinjection wells

Based on estimates of aquifer thickness and hydraulic conductivity (to be provided as input parameters), as well as on the maximum flow rates, analytical solutions of drawdown and capacity of wells in confined or unconfined aquifers determine the necessary number of wells, internal distance, diameters, and filter lengths. Here we use the simplified assumption that all wells shall deliver equally at maximum demand. The potential nominal diameters of the filters are provided by an internal database of typical PVC filter pipes. These data cover the spectrum of wells in unconsolidated rocks.

In regard to the following simulation of long term behaviour, the above mentioned dimensioning of the wells is sufficiently conservative.

HYDRAULIC-THERMAL SIMULATION

Once all necessary input has been provided or determined, the groundwater flow and heat transport simulations can be performed. The simulations are based on annually averaged values of groundwater demand. For the positioning of wells and the postprocessing of results a specialized graphical interface has been developed. After specifying the area of investigation (extension and location, optionally georeferenced by local or country's coordinates) a background plan or map of the site can be imported. Next, the well positions are selected. The tool provides some initial information on the minimum distance between pairs of pumping or injection wells, respectively, as well as between pumping and injection wells (the latter is based on an analytical calculation of thermal breakthrough after 30 years of operation). Positioning of the wells and identification of the groundwater flow direction can be done interactively at the graphical interface, either by drag-and-drop onto the map or by specifying the coordinates.

The governing system of equations for the two-dimensional Darcy flow and the advective and conductive heat transport is solved internally based on a Finite Volume Solution with an optimised discretisation scheme. The size of the model area, the boundary conditions and an appropriate discretisation are chosen internally and are of no concern to the user, apart from the option to choose an overall number of elements. The transient flow and transport problem is solved by a CVODE solver in two steps: first the flow field, followed by the temperature calculations. The solver is an internal component of the tool.

The conductive heat transfer into the cap and bedrock of the aquifer is considered if requested. This process is implemented by calculating one-dimensional transient heat conduction into or from a semi-infinite space. This semi-analytical procedure was described by Vinsome and Westerfield (1980) and has also been implemented in the TOUGH2 code.

Once the calculations are completed - which should not take more than a few minutes on an average desktop machine - the results of the simulation are presented as isolines of temperature and water level change after the operational period. The visualization can then be zoomed to the user's desire. In addition to the visualized results the main parameters for the simulation are displayed (Figure 1).

VERIFICATION

Code verification of our software was performed through a number of comparative calculations with TOUGH2. Due to the fact that TOUGH2 is based on a comparable numerical procedure (Finite Volume), the comparative calculations can be based on an identical discretisation scheme.

Below, we present three comparative examples:

1) one doublet (one pumping and one injection well) with a natural flow field of high velocity (test 1),
2) one doublet in a flow field of low velocity (test 2) and
3) a complex irregular arrangement of four pumping and four injection wells (test 3).

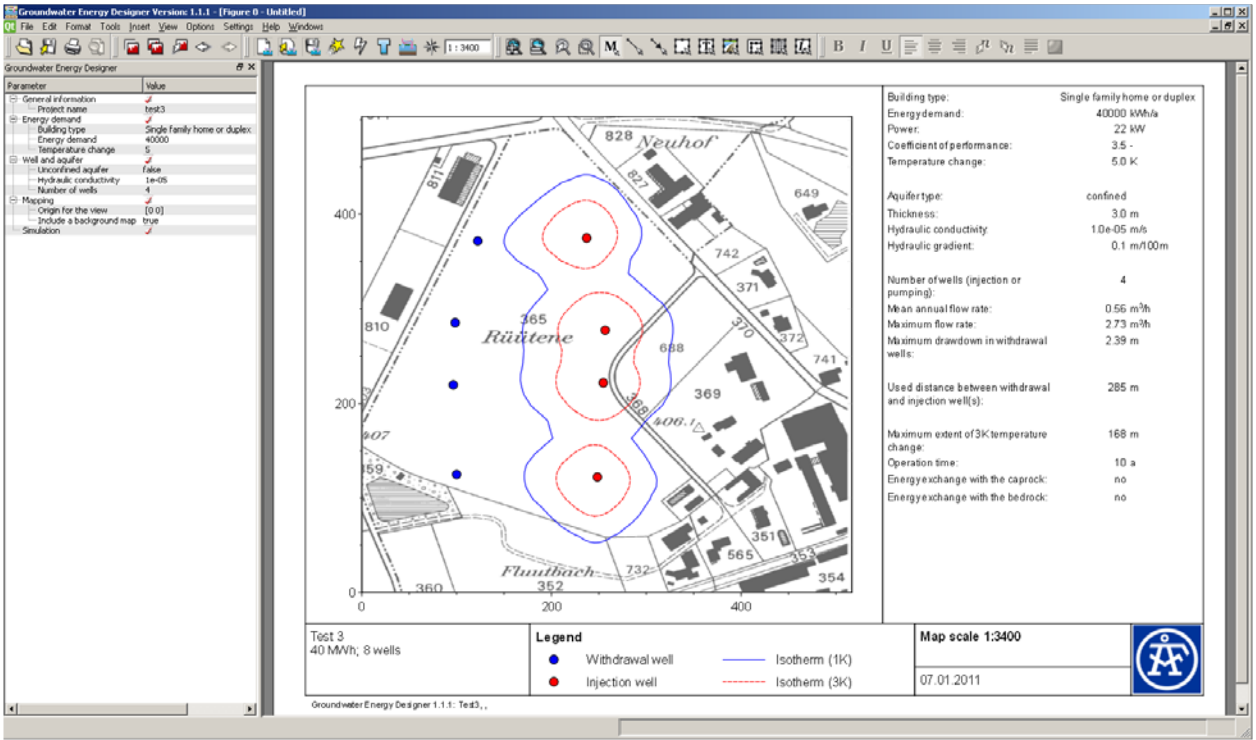

Figure 1: Presentation of results (exemplary).

<u>Assumptions of energy demand:</u>

We assume the following energy demands for the three examples:

<u>Tests 1 and 2:</u>
single or duplex, European style house;
net energy demand: 23.5 MWh/a (~ 1,860 l light fuel oil per year)
heating power: 13 kW
COP of heat pump: 3.5
Mean cooling: 5 K
Yearly average flow value of groundwater circulation: 0.33 m3/h resp. 5.5 l/min

<u>Test 3:</u>
same category of building;
net energy demand 40 MWh/a; 22 kW
same assumptions for COP and temperature change
Yearly average flow value of groundwater circulation: 0.56 m^3/h or 9.4 l/min)

<u>Hydrogeological conditions:</u>

confined aquifer,
thickness: 3m;
porosity: 30%;
gradient of groundwater surface: 0.1m/100m (0.1%)
hydraulic conductivity:

Test 1:	$1{\cdot}10^{-2}$ m/s
Test 2:	$1{\cdot}10^{-4}$ m/s
Test 3:	$1{\cdot}10^{-5}$ m/s.

The chosen hydraulic conductivities largely cover the range of utilised aquifers. Together with the natural gradient of the groundwater surface, they represent a large spectrum of naturally occurring flow velocities.

We use Tecplot, version 10.0, to visualize the comparison of results from GED und TOUGH2.

<u>Results of test 1</u>

The high hydraulic conductivity ($1{\cdot}10^{-2}$ m/s), together with the gradient of 0.1m/100m, yields a high Darcy velocity of 315 m/a. This requires a large extension of the model area in downstream direction to avoid numerical boundary effects (Dirichlet). GED estimates dimensions of 23,600 m downstream and 250 m perpendicular to the natural flow. With the default number of 2,500 elements, this configuration results in a relatively course discretisation at longer distances from the injection point. On the other hand the high natural velocity allows for short distances between pumping and injection wells without running the risk of thermal breakthrough. GED recommends a minimum distance of 2m. For the simulation we choose 5m. Figure 2 shows the relevant section of the model area with results from

GED and TOUGH2 (temperatures after 10 and 30 years of operation).

The high natural flow velocity leads to a distinct long and narrow “plume” in the downstream direction. The 0.5K and 1K isotherms are indicated. The 1K isotherms reach distances of up to 320 m from the injection point and are comparable after 10 and 30 years of operation.

The 3 K isotherm does not extend beyond 15m from the injection point. The results from GED and TOUGH2 are in a good agreement.

The effect of heat transfer from the cap and bedrock is illustrated in Figure 3. The diagram shows the temperatures along a section through both wells parallel to the x-axis (in Figure 2). The temperature change in the nearfield of the injection point, which is relevant for approvability assessment (in Switzerland: limited to 3K over 100m) is barely affected by the heat transfer (3K change occurs at approximately 13 m).

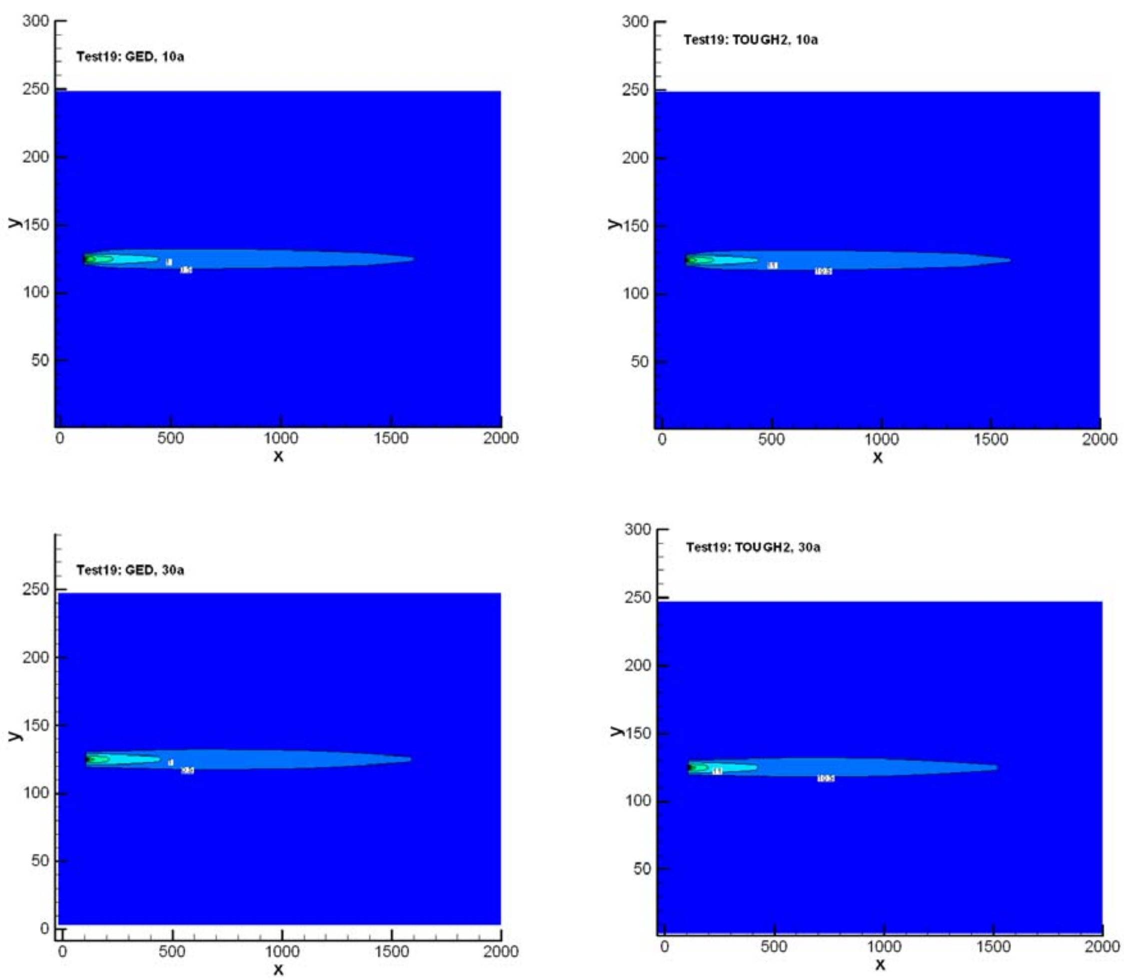

Figure 2: Detail of results: left GED, right TOUGH2, on top after 10 years, on bottom after 30 years of operation [dark blue: unaffected temperatures; isotherms of 0.5K and 1K change indicated[1]].

[1] The reference temperature of the TOUGH2 calculation is chosen here as 10°C. In Figure 2, on the right, the 10.5°C- and 11°C-isothermes after heating by 5K are indicated. For the comparison between GED and TOUGH2, the differences in reference temperatures, heating or cooling are not relevant. GED calculates temperature differences (therefore the 0.5K und 1K-isothermes are shown in Figure 2, on the left).

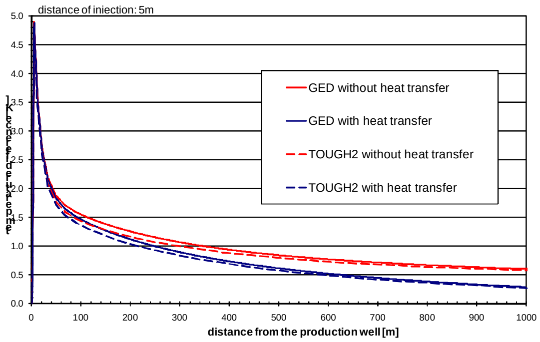

Figure 3: Temperature profile through the „plume" of test 1 after 30 years of operation without (analog to Figure 2 bottom) and with heat transfer (blue).

Results of test 2

Test 2 considers the same configuration and aquifer but with a hydraulic conductivity two orders of magnitude ($1 \cdot 10^{-4}$ m/s) lower. This results in a low Darcy velocity of 3 m/a. GED automatically determines a required model area of 570 m x 260 m (for 30 years of operation).

A direct comparison for 10 and 30 years of operation (and accordingly different areas of required model size) between GED and TOUGH2 is shown in Figure 4. For an operational period of 30 years our chosen distance of 100m between pumping and injection well is proven to be insufficient (GED suggestion is 136m).

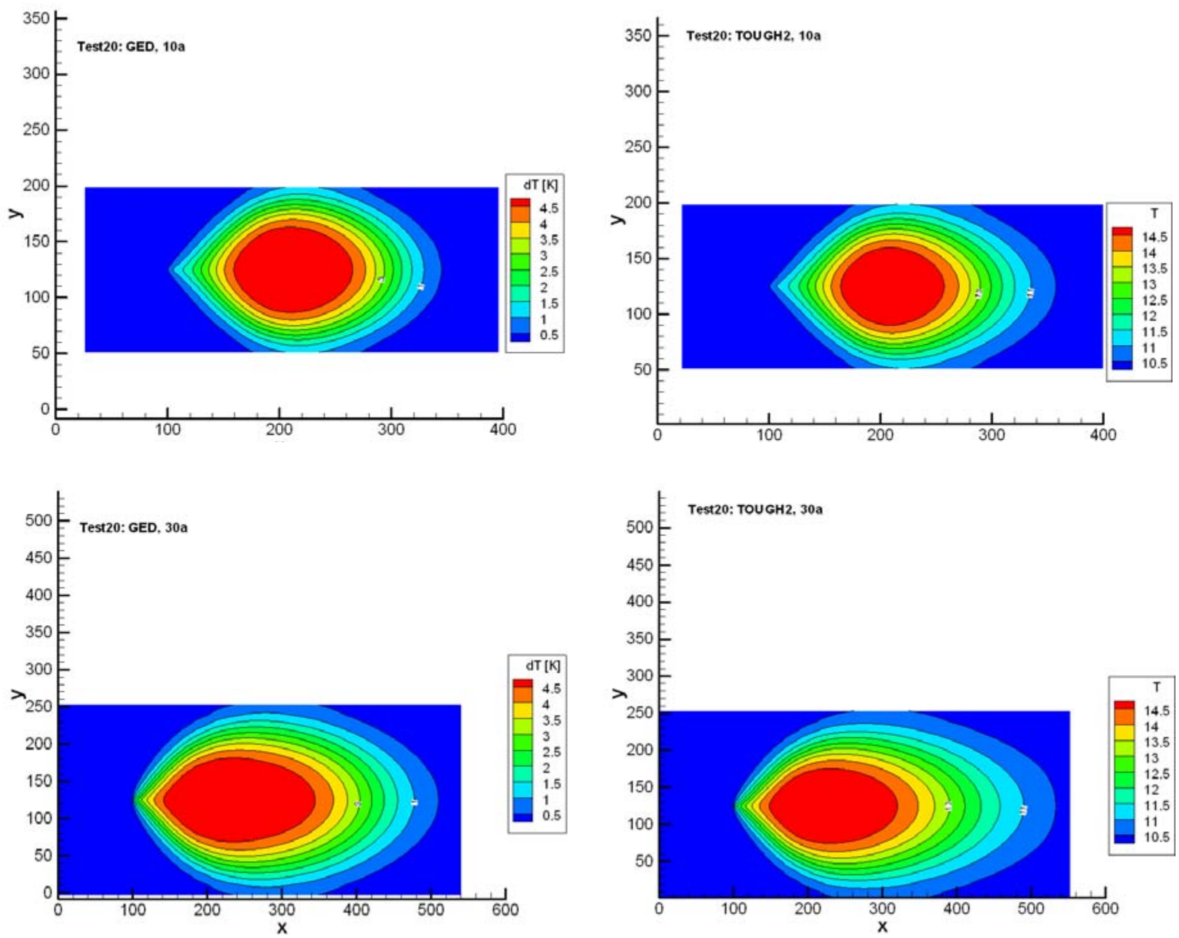

Figure 4: Comparison of results: left GED, right TOUGH2, on top after 10 years, on bottom after 30 years of operation.

Due to the larger involved area, the heat transfer from the cap and bedrock is more important than in test 1. When neglected, the 3K isotherm extends roughly 200 m from the injection point, whereas by consideration its maximal distance from the injection structure is only 26 m when heat transfer from the caprock is included. (Figure 5).

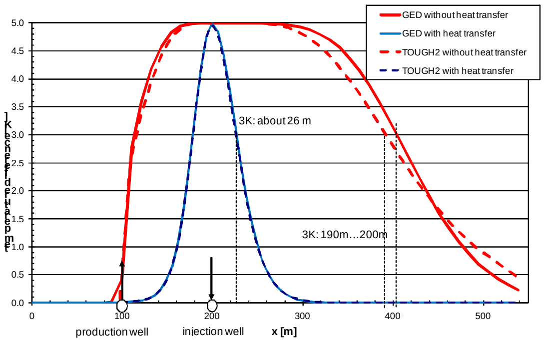

Figure 5: Cross section through the „plume“ of test 2 after 30 years of operation without (analog to Figure 4) and with heat transfer (blue).

Results of test 3

With still lower conductivities and higher demands more wells become necessary. In test 3 we choose 4 pumping and 4 injection wells, which are located more or less arbitrarily. Each well produces or injects 0.14 m^3/h (averaged per year). The calculations are again based on a 5K temperature change. As an example the results from GED and TOUGH2 after 10 years of operation are shown in Figure 6.

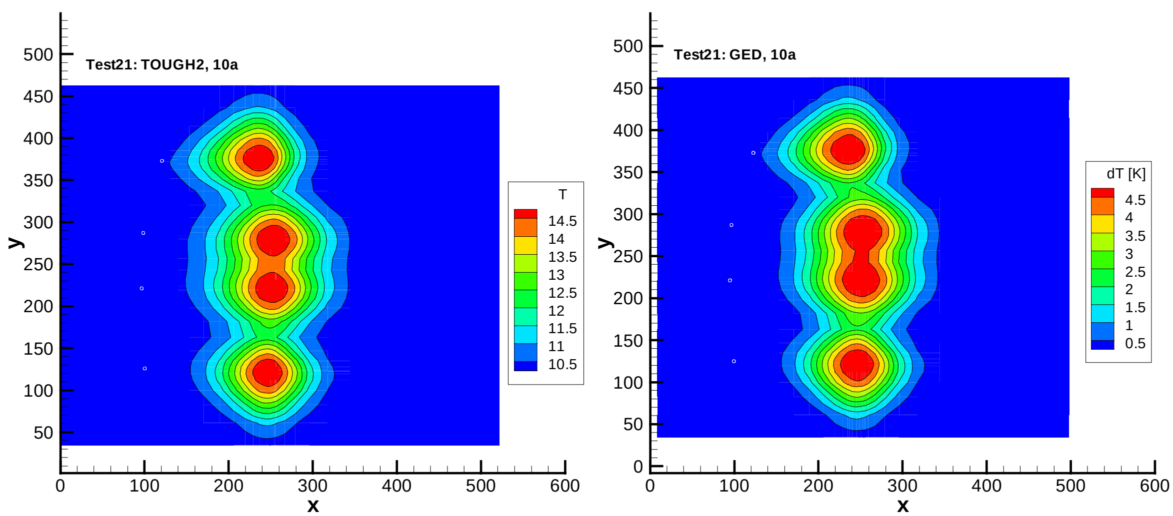

Figure 6: Comparison of the GED and the TOUGH2 results of test 3 (after 10 years).

SUMMARY

GED is a tool aimed at designing groundwater utilization facilities for heating or cooling based on numerical simulations. In order to provide a high level of user-friendliness, speed and robustness we have implemented methods which do not require any previous knowledge of numerical modelling and which are based on comparatively simple assumptions. In the phase of preliminary planning (to test the feasibility and general approvability of the project) these are generally adequate and justified.

This tool is not expected to replace high complexity groundwater modelling, which is generally necessary at larger sites and/or in case of sensitive approval regulations. However it allows the planning engineers of such sites to make scoping considerations in order to check the feasibility and potential capacity for optimizing in a very early phase without far-reaching knowledge of modelling of fluid flow and heat transfer. The integration of an "automatic" numerical simulator without presumptions of the user's knowledge is a novelty. Comparative calculations of pressures (heads) and temperatures with TOUGH2 show agreement, which is - concerning the goal of the tool - appropriate and adequate.

Acknowledgement

We thank the Swiss Federal Office of Energy for supporting the code development financially. The code can be downloaded at http://www.colenco.ch/eng/depts/ge/ged_order.html.

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