CONTEST
Concrete Thermal Energy Storage for Parabolic Trough Plants

A Proposal to the 5th Framework Program of the European Union

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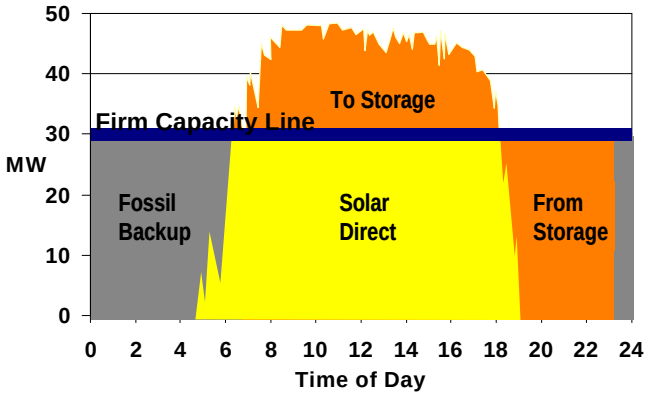
CONTEST - Concrete Thermal Energy Storage

Objectives

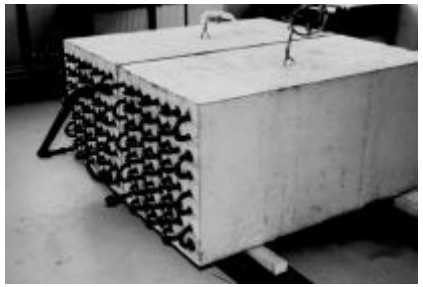


- ***Convert intermittent solar thermal electricity into firm capacity with economic thermal storage.***
- ***Increase solar production hours to over 50% of operation in hybrid systems.***
- ***Achieve total solar thermal production costs of 0.08Euro/kWh and less.***

Intermittency of supply, unpredictable availability and no firm capacity is the problem of renewable energy. The 354MW of successful solar thermal parabolic trough plants in California use 25% natural gas for backup. Within the recent renewable electricity laws of Southern Europe (Greece, Spain, Italy) only pure solar electricity is eligible for premiums. The development of economic thermal storage for the commercial solar thermal plants, now under development in Greece and Spain, is the techno-scientific challenge aimed at in this proposal. Combining the development of a sophisticated high temperature storage matrix of specially defined concrete mixtures with an innovative design of charge/discharge heat exchanger arrays will create an entirely new storage technology for solar thermal parabolic trough plants. CONTEST, a proposal within the EUROTrough cluster, will be an important element to grant a minimum solar share of 50% in hybrid plants and to reach the total cost target for overall electricity production of 0.08Euro/kWh. CONTEST aims to overcome the technical problems related to connections to the grid by leveling of the intermittency of solar radiation and reach system availabilities higher than 95%. CONTEST will be the solution for using solar energy in hybrid fossil/solar plants in more than half of the number of hours/year of operation. Finally CONTEST aims to improve the the acceptability of renewables, by removing to a significant extent the obstacle of intermittency from solar power generation.

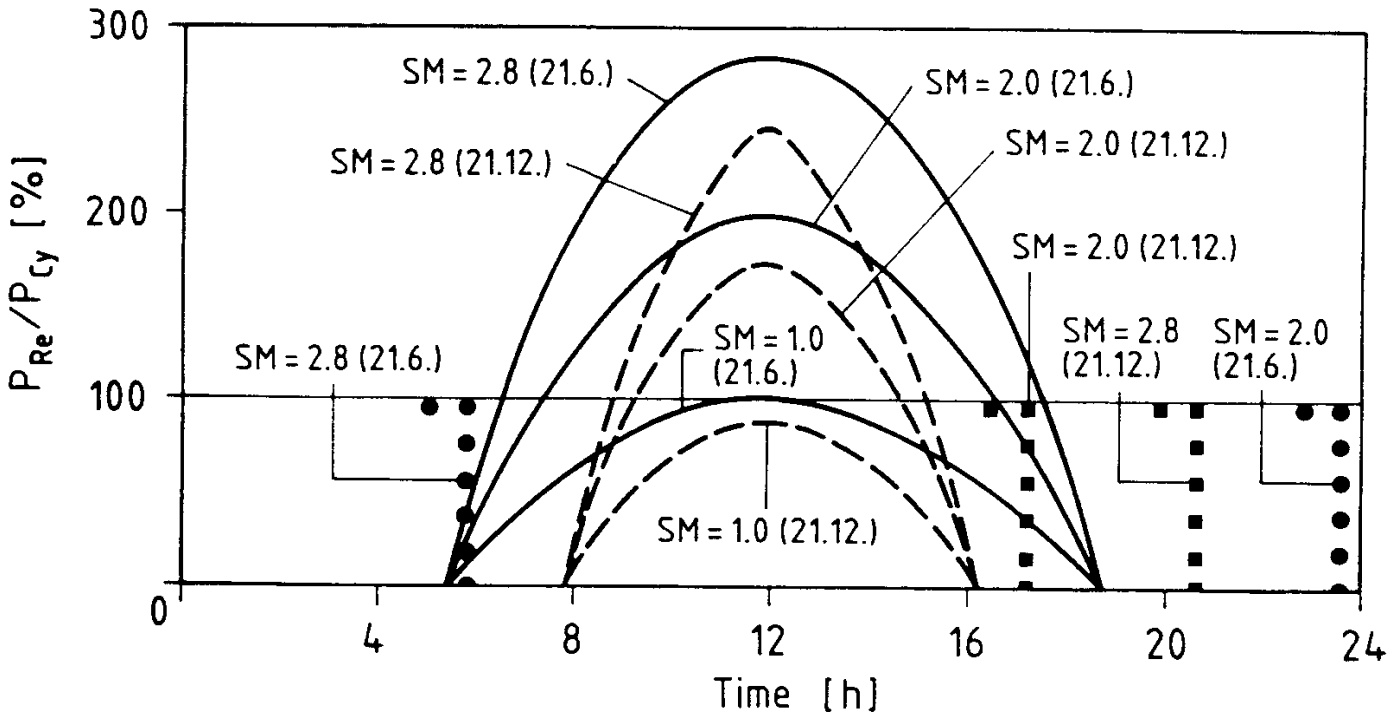
Proposed CONTEST Program of Work

Description of the Work



The scientific/technical work program of CONTEST is a bottom up approach, that starts from successful lab experience with high temperature concrete storage matrices and first bench scale tests , continues with the conceptual design, detailed design, manufacturing, construction, startup and testing of a 1-5MWh CONTEST test module at the Plataforma Solar in Almeria (PSA), Spain, and finally ends with the conceptual design of a full scale 100-200MWh CONTEST commercial module. This problem oriented technology development is supported by scientific investigations on advanced storage matrix materials, thermo-physical and thermochemical lab qualifications, detailed physical-thermodynamical performance analysis and material research. The techno-economic performance and environmental benefits of the CONTEST concept will be continously monitored by a potential user of the technology.

Extension of Solar Operation with Storage at Almeria



Achievable rated power operating hours on a cloudless December 21st and June 21st for SM ranging from 1.0 to 2.8 in Almería, Spain. Wile the SM 2.8 is sufficient to operate 24 hours in summer, only 12 hours are possible with it in winter, and a minimum SM of 5 would be required to achieve 24-hour operation in winter.

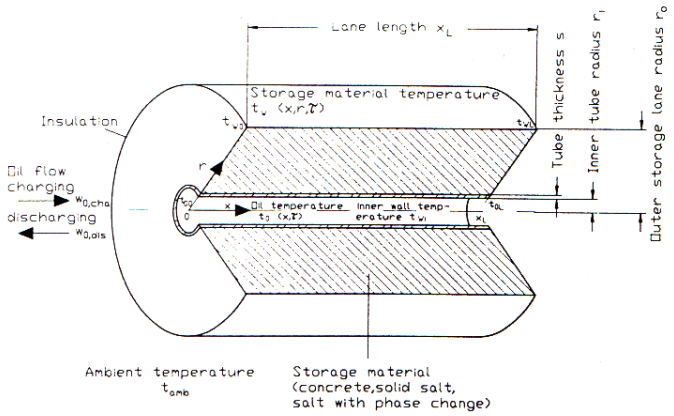
CONTEST Proposal Cost Targets

5.2.4. Solar thermal systems

For solar thermal concentrating systems, the total cost targets in the short to medium term are 2500Euro/kW_e for installation and, in addition for hybrid production, the total cost target for overall electricity production 0.08Euro/kWh with an annual solar contribution of at least 50%. Thermal storage capacities of at least 3 full load hours are required to extend solar power generation beyond sunset, when most sunbelt countries have their evening load peak. Investment costs of 25Euro per kWh of utilizable storage capacity is the CONTEST cost target that will significantly contribute to reach the community's target to reduce solar thermal generation costs by half to 0,04Euro/kWh.

CONTEST Proposal R&D Objectives

Technical Risks and Problems to be Resolved through Research and Development in the CONTEST Project



Physical storage model

Heat Transfer Model

- ⇨ Identification and thermophysical/-chemical qualification of a suitable basalt concrete that will survive 30 years of charge/discharge cycles at 200/400°C.
- ⇨ Development and qualification of a suitable concrete matrix with reinforcement elements that will adapt the thermal expansion coefficients the best possible to the ones of the charge/discharge heat exchanger arrays.
- ⇨ Minimization of thermal cracking of the concrete storage matrix during the charge/discharge cycles
- ⇨ Avoidance of gap formation between the heat exchanger tubes and the high temperature concrete matrix
- ⇨ Maximization of heat capacity of the high temperature concrete storage matrix
- ⇨ Optimization of the heat transfer between the heat exchanger tubes and the high temperature concrete storage matrix during charge and discharge
- ⇨ Optimization of the heat transfer within the high temperature concrete storage matrix itself
- ⇨ Minimization of thermomechanic stresses of the up to 500m heat exchanger array bundles and their joints
- ⇨ Expulsion of the chemical water after concrete casting and first heat up procedure to 300°C
- ⇨ Insulation of the CONTEST to the ground and to the ambient
- ⇨ Minimization of pressure losses to minimize parasitic pumping power

CONTEST Proposal Targets & Deliverables

Quantitative Targets and Deliverables

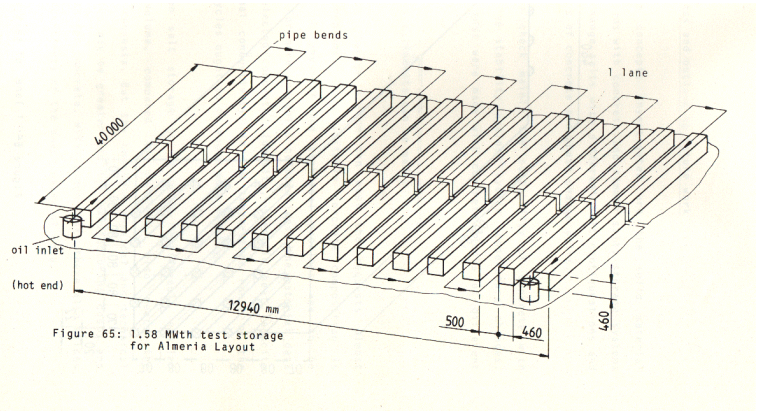


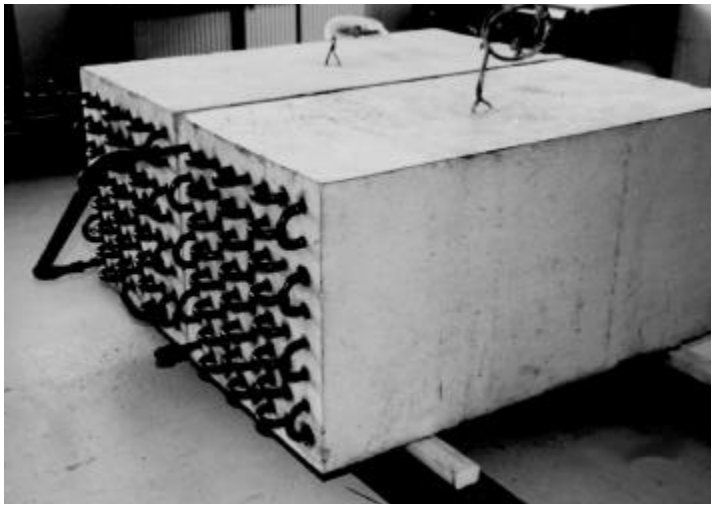
Figure 65: 1.58 MWth test storage for Almeria Layout

1-5MWh CONTEST Prototype Storage to be built at the PSA in Almeria

- ⇨ Qualify with lab research the high temperature storage concrete aggregates, composition, water/cement ratio and reinforcement elements (like steel needles) to achieve a volumetric heat capacity of 0.85kJ/kgK, a heat conductivity of 1.5W/mK and a specific cost less than 0.1 Euro/kg.
- ⇨ Design and construct a 1-5MWh CONTEST test module
- ⇨ Startup, Test and evaluate this test module with the existing ACUREX parabolic trough field at the Plataforma Solar de Almería at charge temepratures up to 300°C and discharge temperatures down to 100°C
- ⇨ Identify on basis of typical load curves and available compensation tariffs the optimum commercial CONTEST module size, operation, its interface between parabolic trough field and steam plant / combined cycle and its economically optimized operation, in order to achieve the community total production cost target of 0.08Euro/kWh
- ⇨ Develop a conceptual design of such commercial CONTEST storage modules, that meet the cost target of 25 EURO/kWh storage capacity and operate between 200°C and 400°C.

CONTEST Proposal Innovations

Innovation of the CONTEST Concept



CONTEST Concrete Storage Probes

The concept of using a high temperature concrete storage matrix as economic, large scale bulk thermal storage for solar thermal plants is entirely new and has the following advantages:

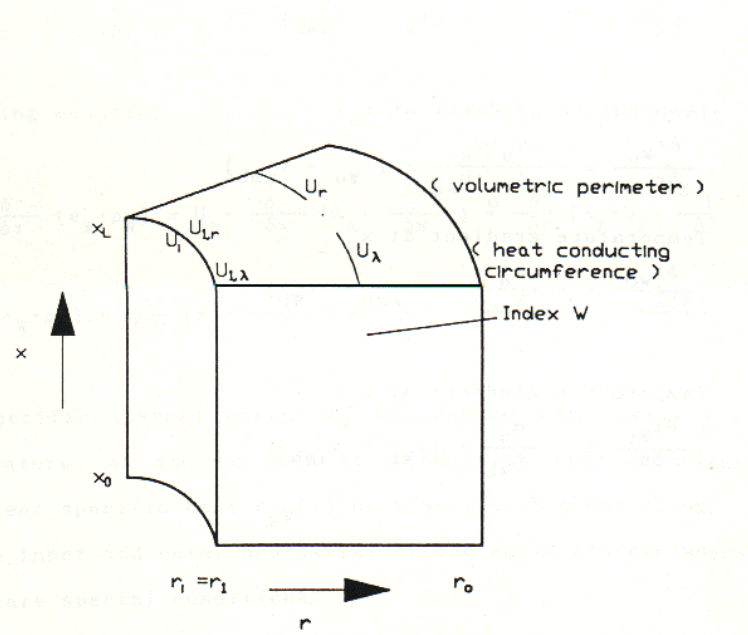
- ⇨ Low cost
- ⇨ Easy on site processing
- ⇨ Adapted technology that can be implemented in the sunbelt countries
- ⇨ High specific heat
- ⇨ Good mechanical properties (compressive and tensile strength, etc.)
- ⇨ Thermal expansion coefficient near that of steel (pipe material)
- ⇨ Aggregates to the concrete available everywhere cheaply
- ⇨ Highly mechanical resistance to cyclic thermal loading

Innovative technological and engineering solutions must be developed to bring this concept into the power market:

- ⇨ concrete composition, aggregates and reinforcement
- ⇨ charge/discharge heat exchanger arrays, their fabriication and maintenance
- ⇨ ground insulation able to support the weight of the storage module
- ⇨ insulation concept, that still allows inspection and maintenance
- ⇨ first warmup procedure and chemical water expulsion

CONTEST Proposal Technical Risks

Technical Risks of the CONTEST Concept



General two-dimensional case of solid storage system

When concrete is subjected to heat, a number of transformations and reactions take place which have influence the strength and other physical properties of the concrete. When concrete is heated, at about 100°C water is expelled. Up to 130 kg of water per m^3 of concrete can be extracted in this way. Remaining water, either physically bound in smaller pores or held by chemisorption, is expelled between 120 and 600°C, which releases another 50 to 60 kg/m^3 of water. Dehydration occurs between 30 and 300°C. This water loss reduces weight by 2-4%. Resistance to thermal cycling depends on the thermal expansion coefficients of the materials used in the concrete. In order to minimize this, a basalt concrete will be selected. Steel needles and reinforcement may be added to the concrete to impede cracking. By doing so, the thermal conductivity is increased about 15% at 100°C and 10% at 250°C.

The research, development and engineering efforts in the CONTEST project have to address and minimize the following technical risks:

- ⇨ Cracking and loss of mechanical resistance of the concrete matrix
- ⇨ Gap formation between concrete and tubes
- ⇨ Heat exchanger tube rupture because of expansion/contraction cycles
- ⇨ Heat exchanger tube failure due to corrosion

1-5MWht CONTEST Pilot Storage for PSA

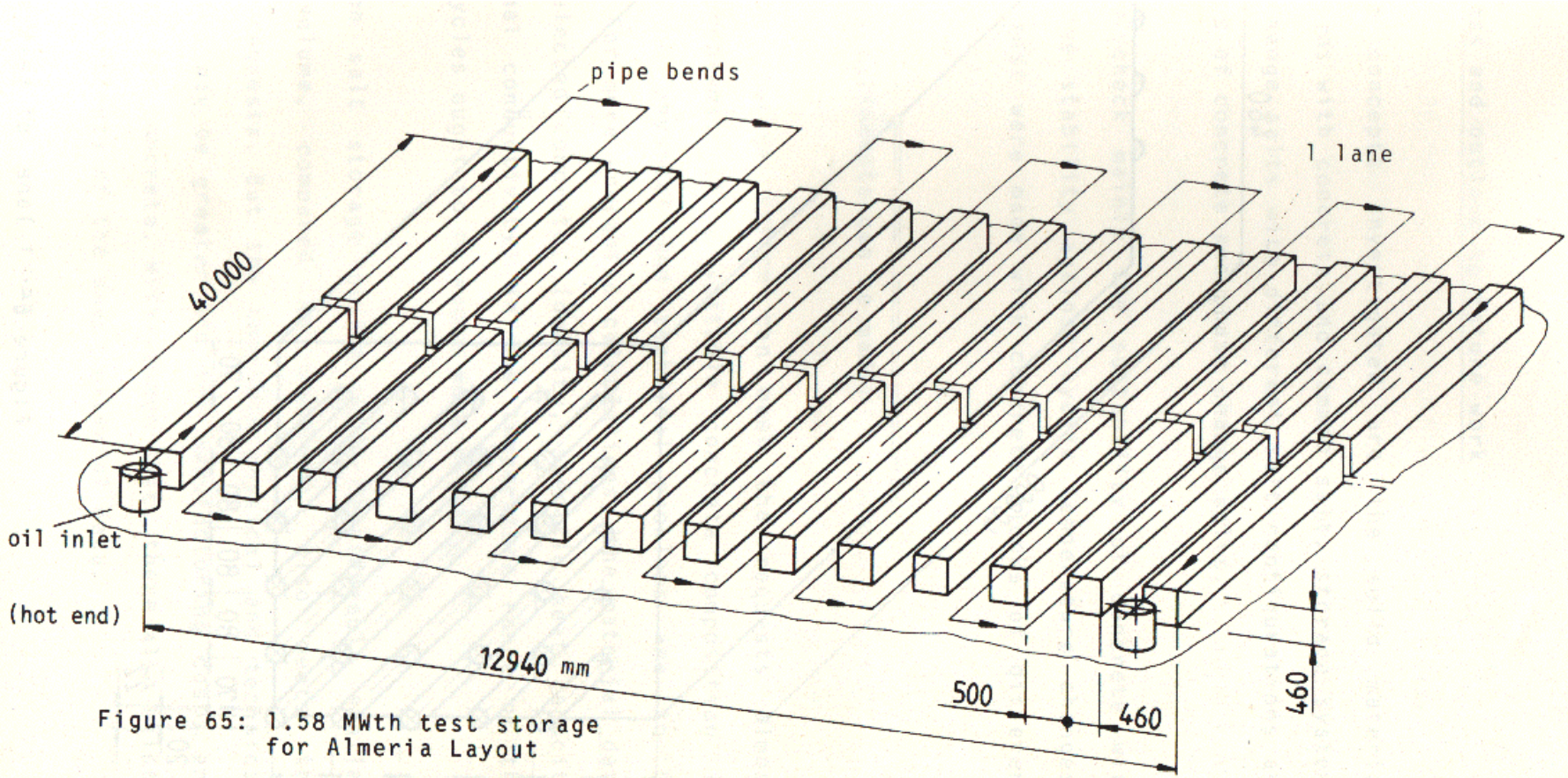


Figure 65: 1.58 MWth test storage for Almeria Layout

Temperature profiles in a concrete storage during the charge/discharge cycle

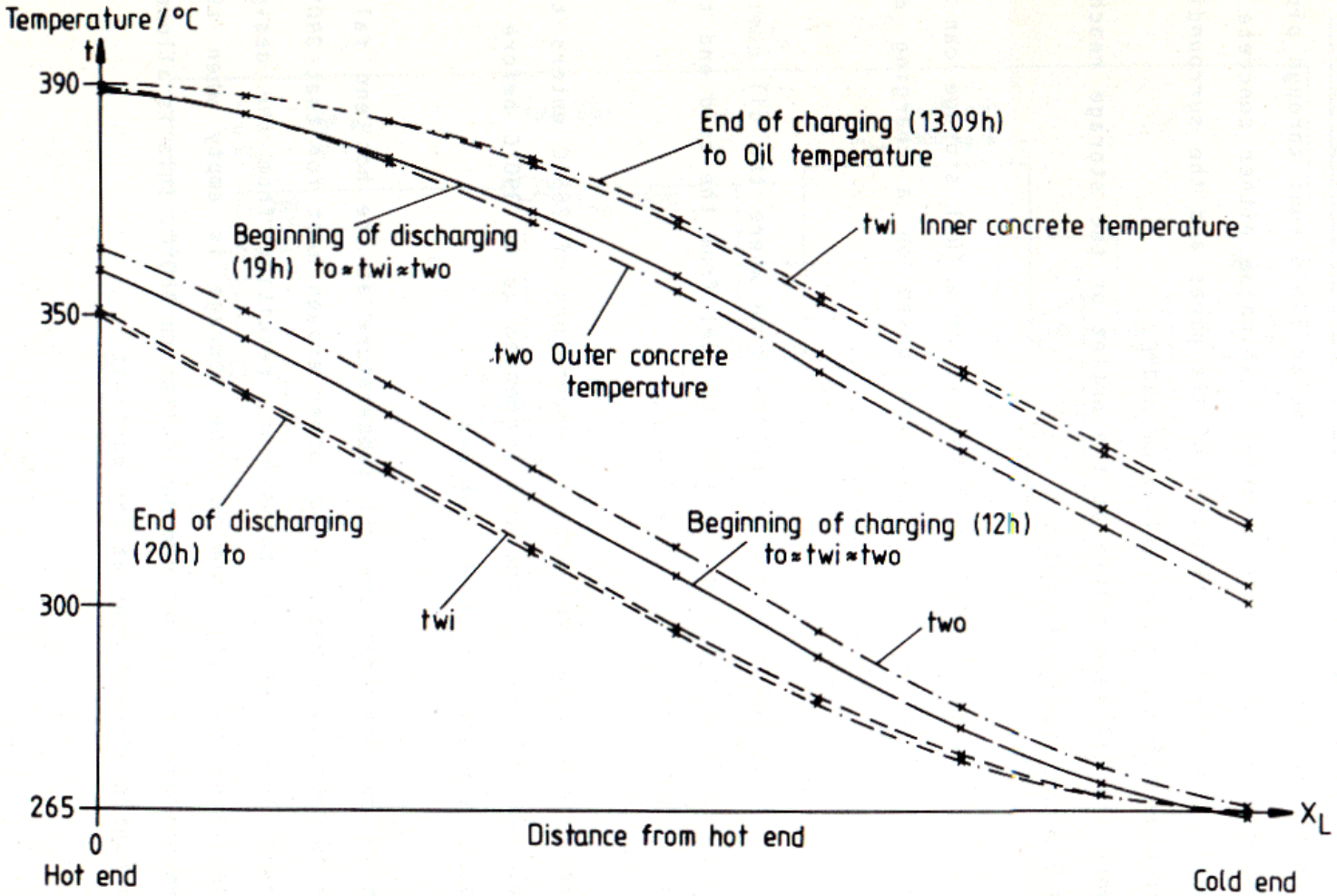
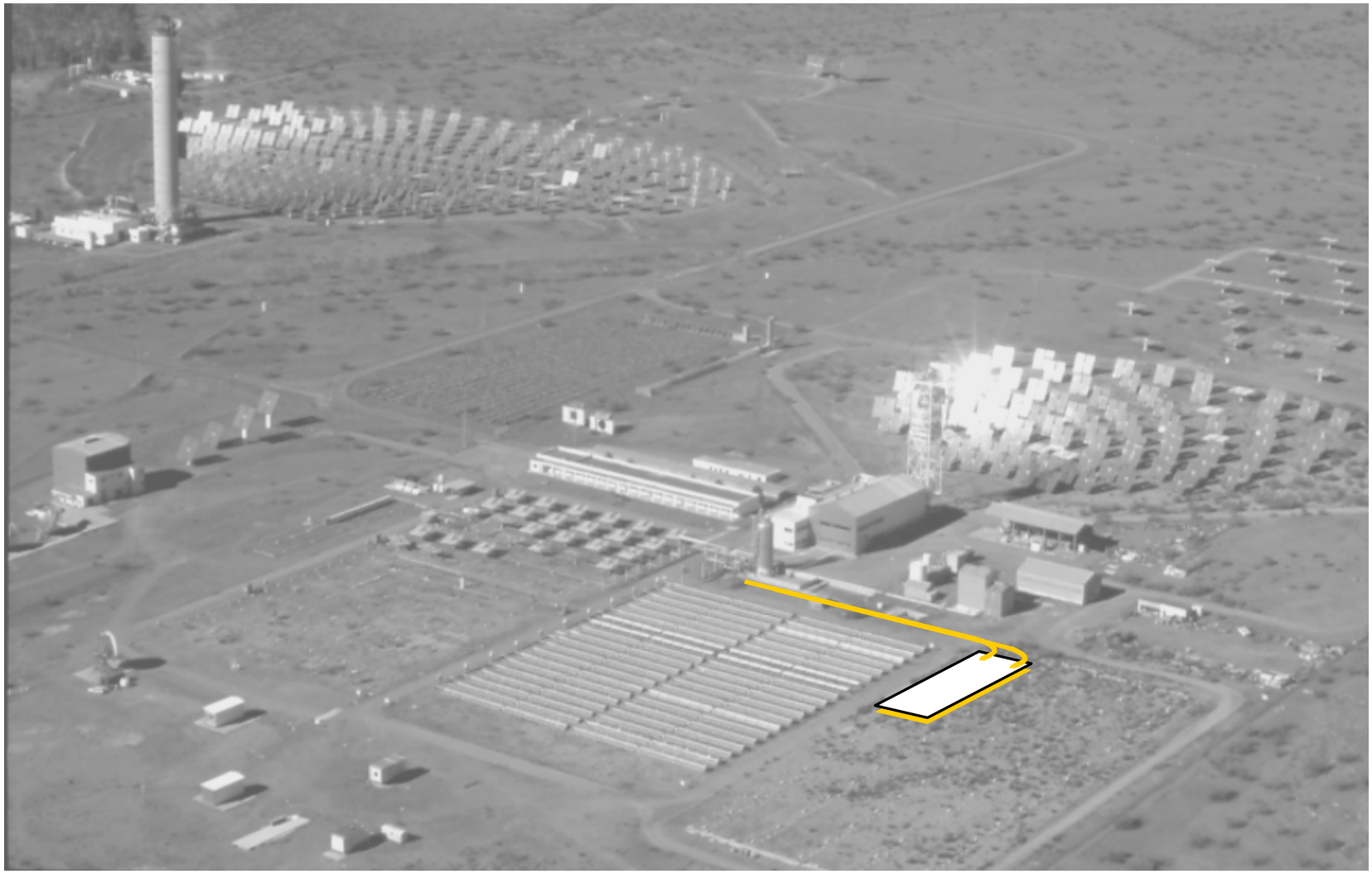
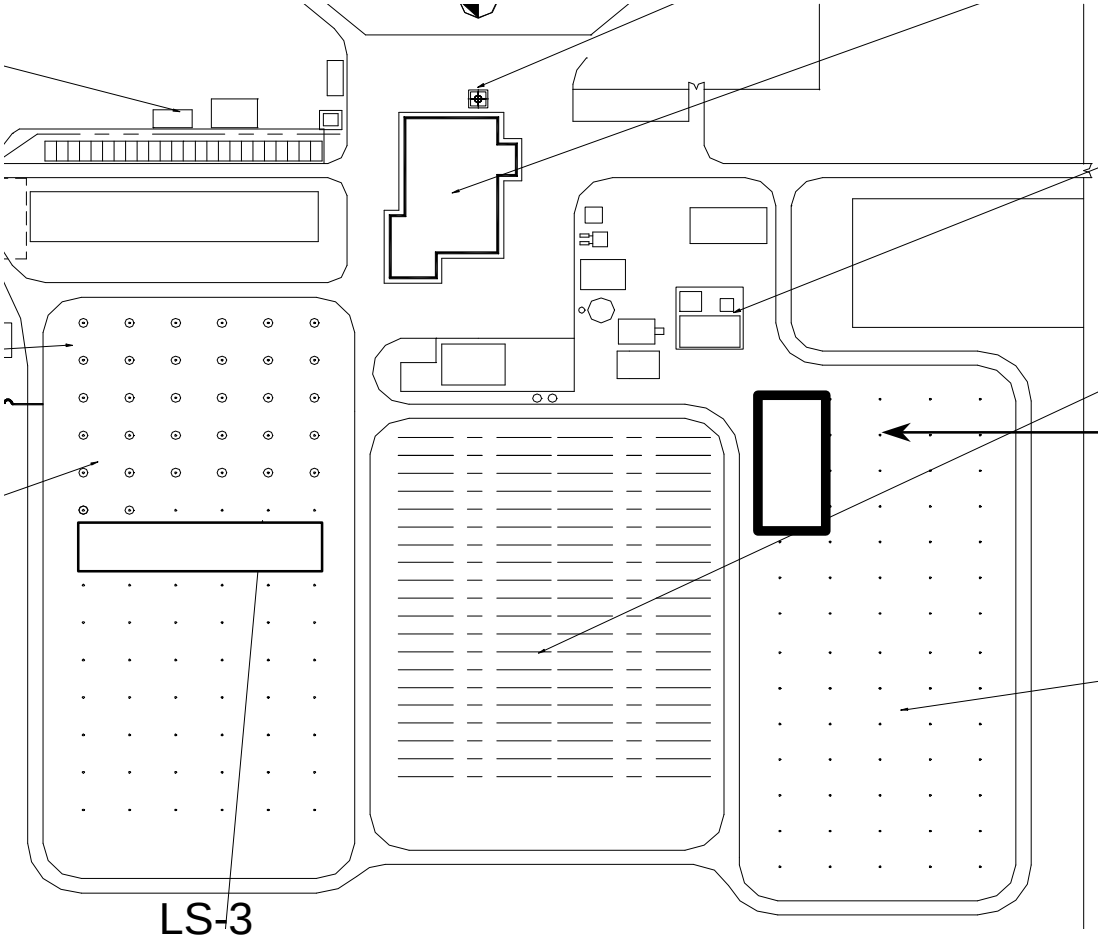


Figure 2: Temperature distribution at different times
concrete with d_i = 20 mm and d_o = 70 mm

Integration of the 1-5MWh CONTEST Storage at PSA



Footprint of the CONTEST Storage at PSA



power block

desalination plant

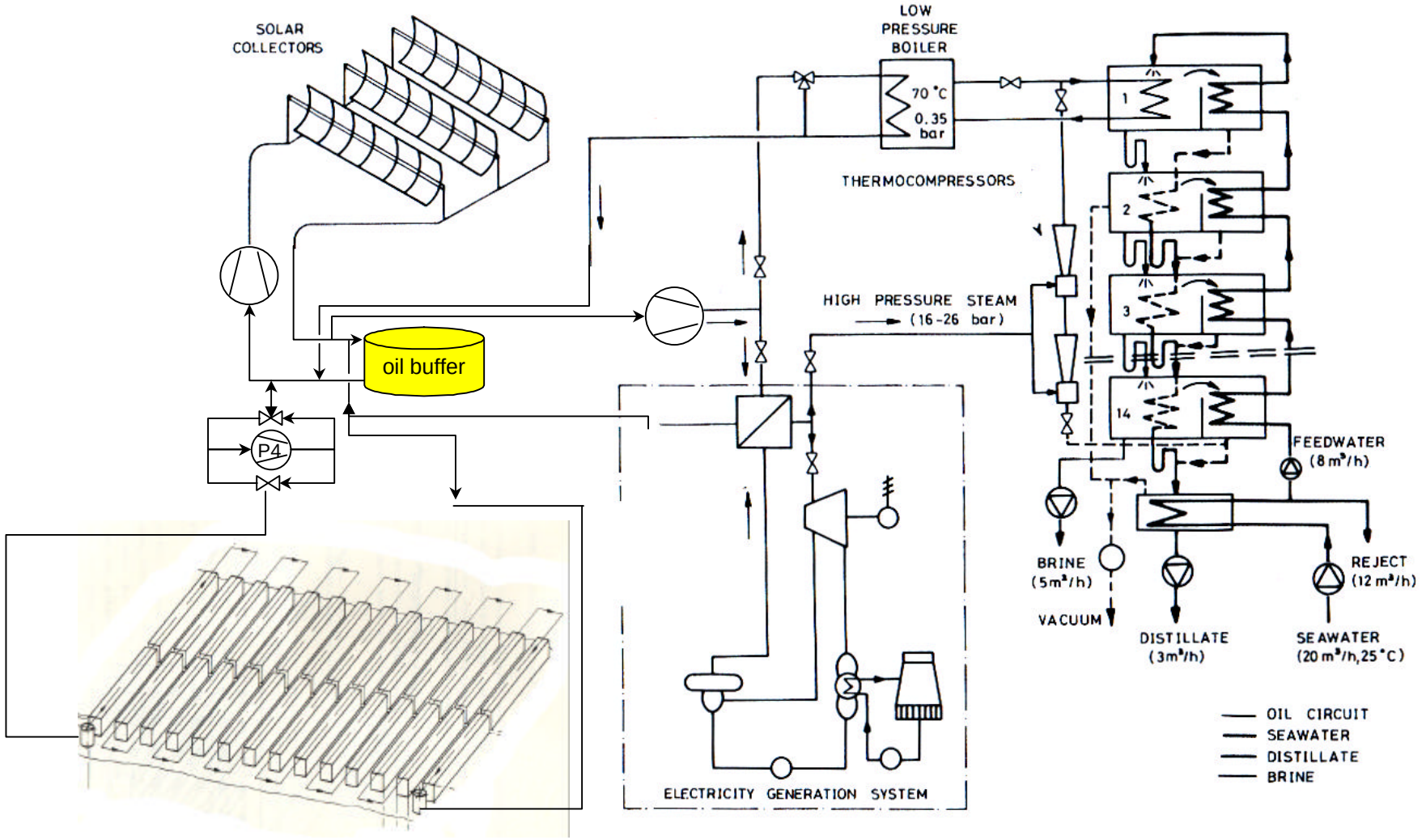
Acurex
collector field

location of
1-5 MWh CONTEST
storage prototype

LS-3
test collector

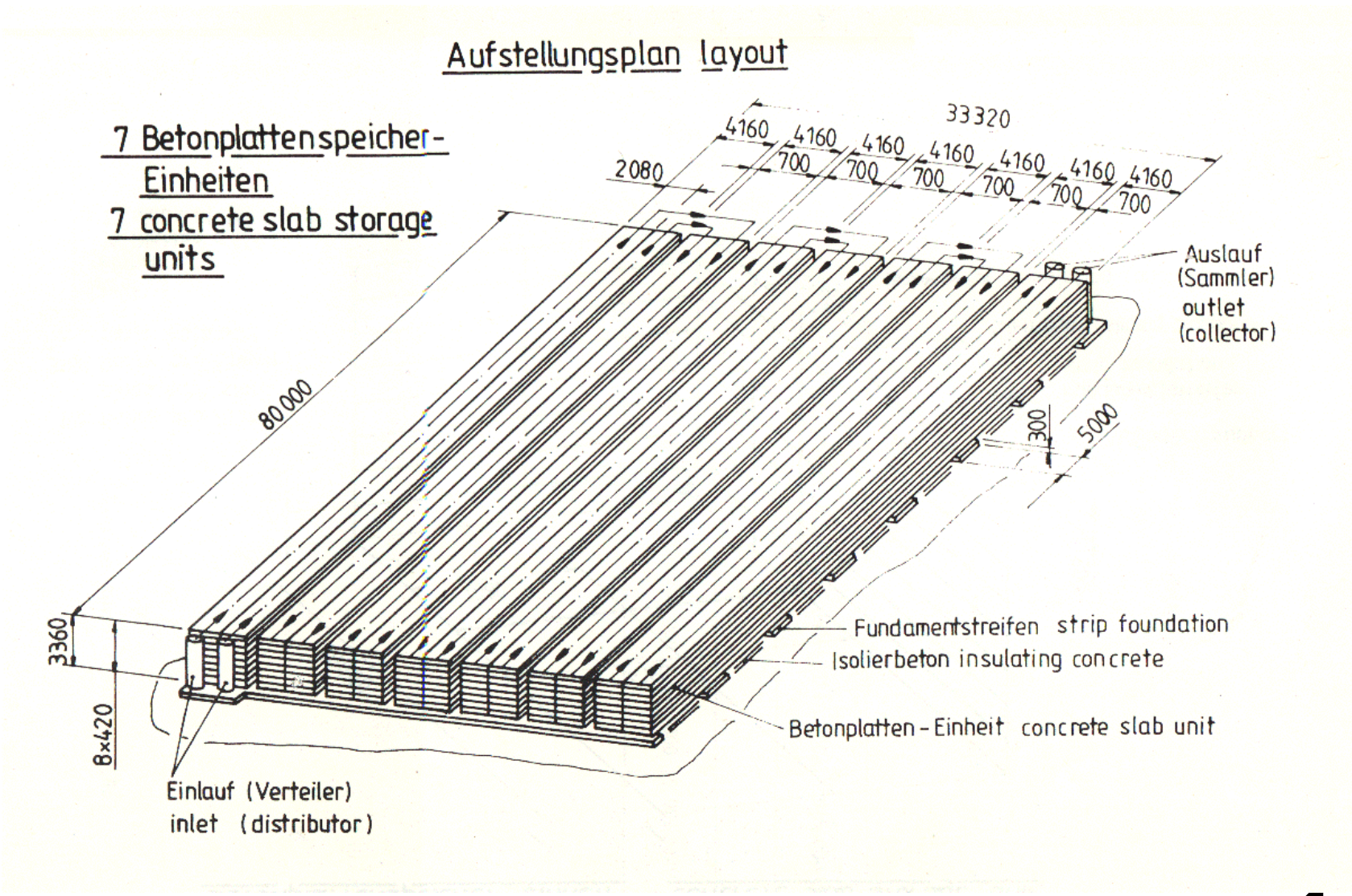
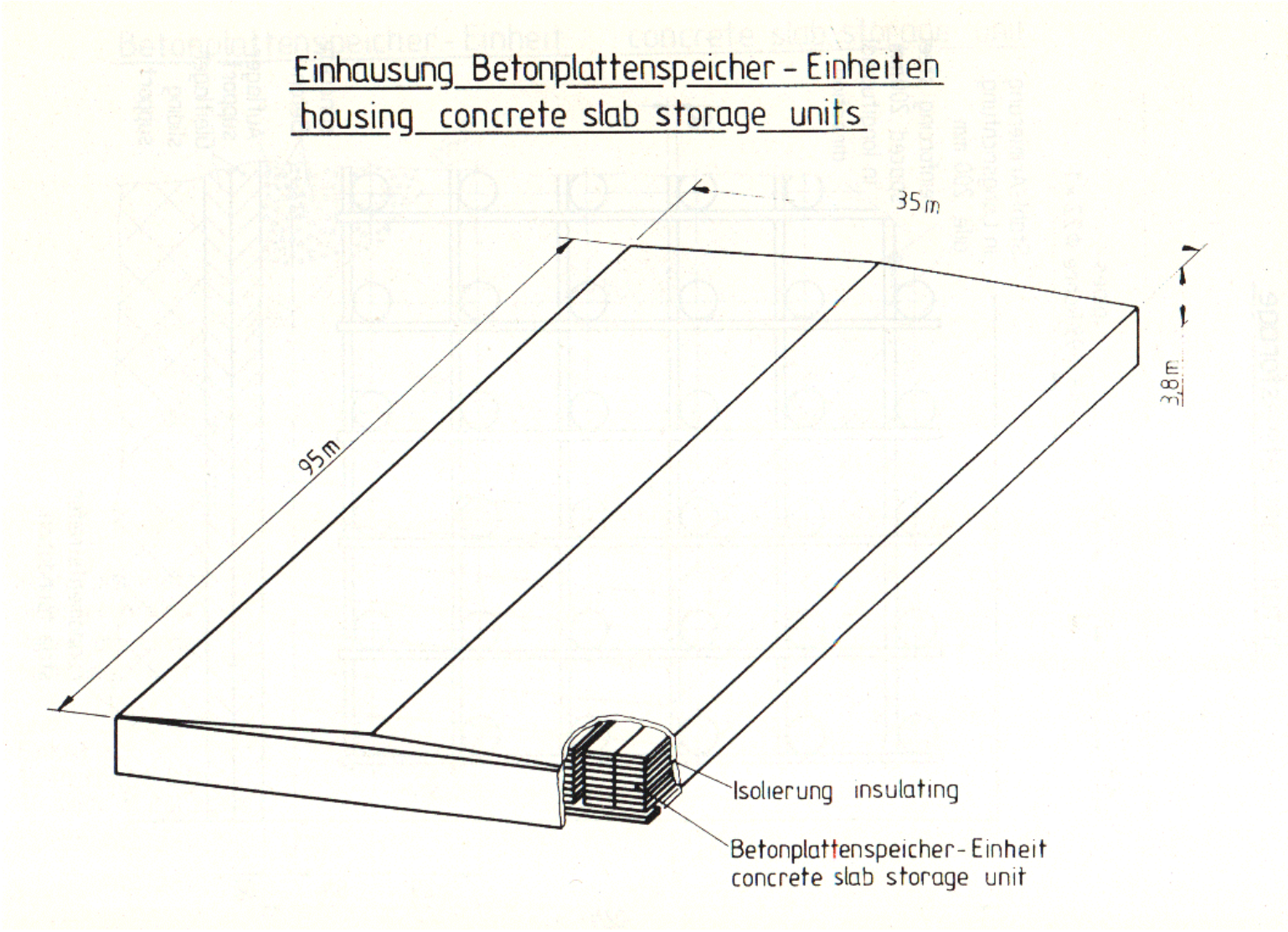
DLR

CONTEST Test Cycle Scheme at PSA



1-5MWh *CONTEST* Storage Prototype

200MWh Commercial CONTEST Storage



200MWh CONTEST Commercial Storage