

THE LRC CONCEPT AND THE DEMONSTRATION PLANT IN SWEDEN – A NEW APPROACH TO COMMERCIAL GAS STORAGE

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1. INTRODUCTION

The Lined Rock Cavern (LRC) concept is a new technology for underground storage of natural gas. This storage combines modern technology, safety and environmental thinking. The main principle is to store gas at high pressures (15-30 MPa) in lined rock caverns at relatively shallow depths (100-200m). The rock absorbs the pressure load and the lining ensures gas tightness. A patent has been developed by GAZ DE FRANCE and SYDKRAFT, two major European energy companies.

The LRC concept has been developed to meet peak demand throughout the year. Other characteristics are a potentially wide geographical/ geological adaptability, low environmental impact and high deliverability and turnover rates. An LRC plant also makes it possible to meet a growing storage demand by stepwise enlargement through addition of new caverns.

An original system for heating or cooling gas (also patented) has been created to reduce the temperature variations inside the cavern. This new technology improves the working gas amount and lowers the specific storage cost. The design can be adjusted for multi-cycling by increasing the capacity of injection/withdrawal in short time. Moreover, the cushion gas amount is very low, approximately 10% of the total gas capacity.

2. HISTORY

The LRC concept has been essentially initiated in Sweden in the 1980's. Its first steps of development included theoretical studies, laboratory tests and field tests in a Pilot Plant at Grängesberg, Sweden (1988-1993), see Figure 1. One of the test caverns withstood successfully a pressure exceeding 50 MPa.

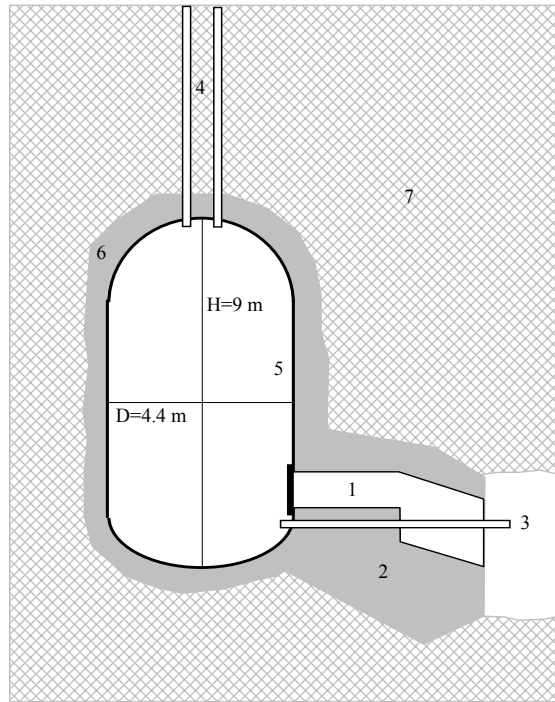


Figure 1. General layout of Pilot Plant cavern.

1. Access tube, 2. Concrete barrier, 3. Water fill, 4. Gas fill, 5. Steel lining (6 mm), 6. Concrete lining (0.6 m), 7. Rock mass.

The concept was originally intended to meet the existing Swedish storage demand, but it was soon realised that it could also have potential for the worldwide gas storage market, especially for the peak-shaving niche.

In 1996-1997, GAZ DE FRANCE and SYDKRAFT formed a consortium with the objective to prepare a basis for decision to invest in a Demonstration Plant (half scale of the industrial size cavern). A great number of studies were made at that time in order to evaluate the technical and economical risks, as well as the potentials connected to the proposed Demonstration Project.

Based on the positive results from the feasibility studies, a decision was taken by the consortium in 1998 to build a Demonstration Plant. The LRC Demo Project is further described in Chapter 5.

3. DESCRIPTION OF AN LRC STORAGE PLANT

A typical LRC storage plant is composed by two main parts, the below ground facility with one or several storage caverns and the above ground facility for handling of the gas, see Figure 2.

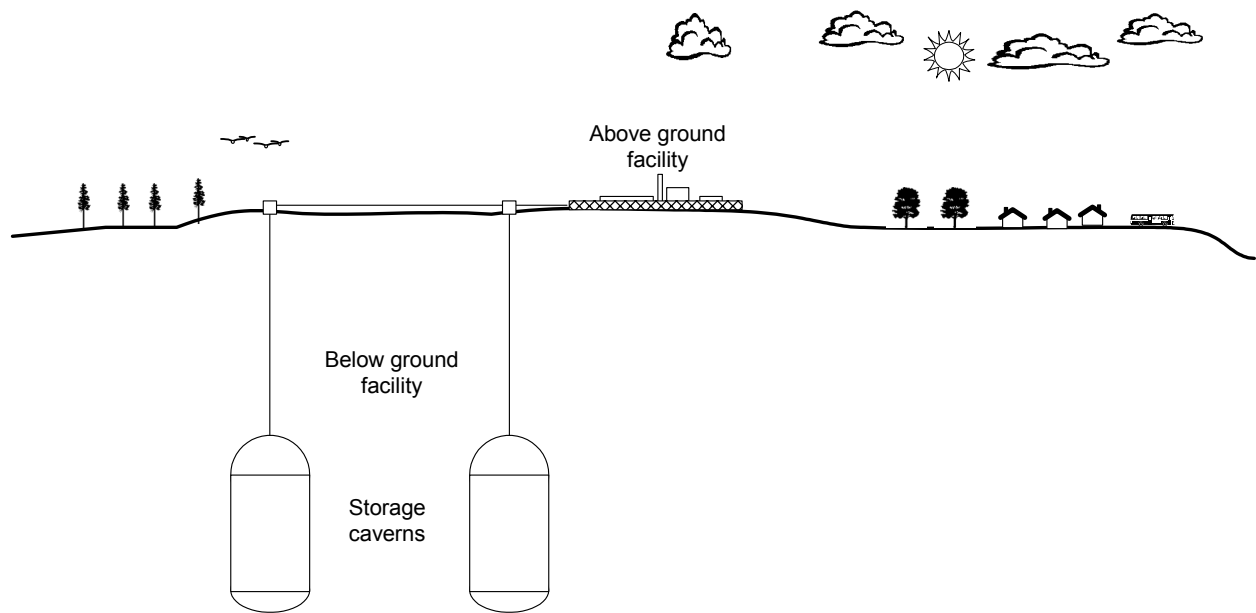


Figure 2. Principle layout of an LRC storage facility

3.1 Underground Facilities

The underground facilities consist of one or more storage caverns, a vertical shaft for each cavern, and a system of tunnels connecting the caverns with the ground surface. The storage caverns are excavated in rock as vertical cylinders with a half spherical top cupola and a flattened half spherical bottom. The caverns are located at a depth of about 100-200 meters below ground.

The maximum storage pressure is in the range of 15-30 MPa, with typical cavern dimensions of 35-40 meters in diameter, 60-100 meters in height, and 12-30 million Nm³ of natural gas storage (working volume) capacity. Any desired total storage volume can be achieved by building the appropriate number of caverns (module thinking). Each cavern is linked to the above ground facilities by a gas pipeline running through the vertical shaft.

3.2 Above Ground Facilities

The surface facilities are similar to that of a salt cavern storage. They include a compressor station, heating/cooling equipment, piping, valves, metering, and control system. The three main differences come from the characteristics of the LRC concept: gastight steel lining, low surrounding groundwater pressure and low temperature.

The steel lining keeps the gas separated from the surrounding rock material and the groundwater at all times. There is thus no need for gas treatment.

The low surrounding water pressure (1 to 2 MPa) allows the minimum operating pressure of an LRC storage to be as low as 2 MPa (usually 8 MPa for salt caverns). This pressure being less than the gas pipe pressure, compression is needed to withdraw gas from the cavern at pressure between the pipe pressure and the 2 MPa.

The low surrounding temperature (10 to 20°C) allows some optimisation of the temperature of the gas stored inside the cavern. This optimisation requires cooling the gas inside the cavern at high pressure, and heating of the gas inside the cavern at low pressure. This is done by withdrawing a part

of the gas, cooling/heating it, and re-injecting it in the cavern. The original circulation system (patented) was created to improve the working gas amount and to lower the specific storage cost.

4. THE LRC STORAGE CONCEPT

Usually, at a depth of 200 m it is possible to store gas at 2 MPa for aquifers and 4 MPa for salt caverns. The LRC technology is planned to store gas at 15 to 30 MPa. The reasons for these differences are related to the basic principles of the storage concepts; aquifers rely on ground water pressure, salt caverns use ground weight and LRC utilises rock strength. Therefore, the geological requirements for localisation of LRC storages are related to the rock mass quality.

The technology of LRC concept is mainly connected to the below ground part, in particular the storage cavern wall. It consists of four structural parts, each one with its own specific function. The LRC cavern wall design is based on the combination of four key components (see Figure 3); the rock mass, the concrete layer, the steel lining and the drainage system.

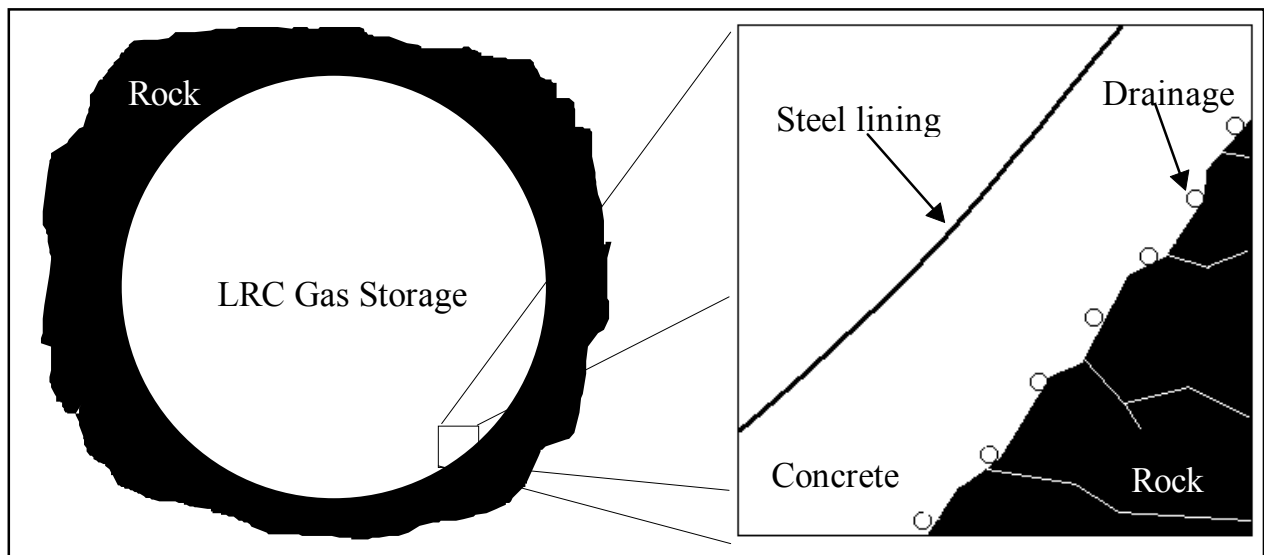


Figure 3. Horizontal section of the cavern wall

Rock mass

The surrounding rock mass carries the gas pressure load and thus acts as pressure absorber. The rock mass is deformed by the gas pressure load, causing the cavern to expand. This will in turn cause strain in the lining. The rock mass must thus be sufficiently stiff to keep the lining strain below the tolerable limit.

A certain thickness of rock coverage is required to prevent the rock mass from uplifting when the cavern is pressurised.

Concrete layer

The concrete layer is placed between the rock and the steel lining. Steel reinforcement is used to control the cracking of the concrete due to the cavern expansion. The purpose of this concrete layer is two-fold:

- to transfer the load generated by the gas pressure in the cavern to the surrounding rock masses
- to provide a smooth base for the lining

Steel lining

The thin steel lining made of 12-15 mm thick carbon steel has the role of achieving absolute gas tightness. It encloses the gas in the cavern and also bridges minor cracks in the concrete surface. From the structural stand point lining is not supposed to carry primary loads as it is supported by the concrete layer, which in turn is supported by the surrounding rock mass. The lining shall however be able to resist the stress and strain caused by the general deformation of the cavern wall.

The maximum operating pressure permissible for the storage depends on the lining characteristics and the geological conditions. It must be set at a value such that the induced deformation in the rock mass and the concrete layer does not strain the lining in excess of its capacity of deformation.

Drainage system

The drainage system consists of a mesh pattern of perforated drainage pipes located in the concrete layer near the rock surface. The system has two main functions: it shall detect, collect and evacuate gas in case of a leak in the steel liner and it shall also drain the ground water to decrease the outside pressure against the steel liner when the cavern pressure is low (e.g. during the construction period).

5. THE LRC DEMONSTRATION PLANT IN SWEDEN

The LRC Demo Project is a joint venture between GAZ DE FRANCE and SYDKRAFT. The project is partially funded by the European Union through the Thermie research and development programme. The goal of the project is to demonstrate the feasibility of the LRC technology by constructing a demonstration scale storage plant (the cavern size of the Demo Plant is about half the size of what is planned for a commercial plant).

The LRC Demo Plant is situated near the coastal city of Halmstad in southwestern Sweden, see Figure 4. The site is near the main gas pipeline along the Swedish west coast and is a good point to serve the Swedish gas market. Construction works started in the end of 1998.

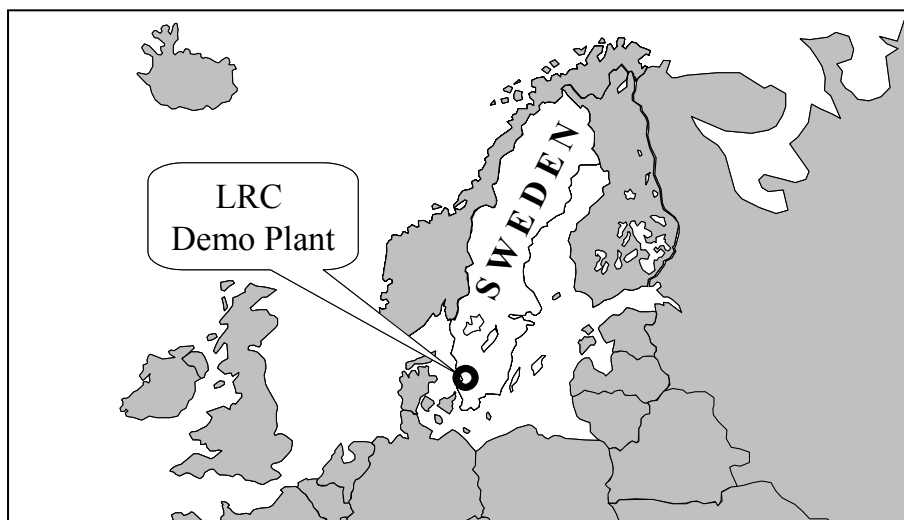


Figure 4. Location of the LRC Demo Plant in Sweden

The LRC Demo Plant consists mainly of the above ground facility, the underground lined storage cavern and the connecting pipeline to the gas grid. Access to the cavern during excavation and construction is provided by a system of transport tunnels, see Figure 5.

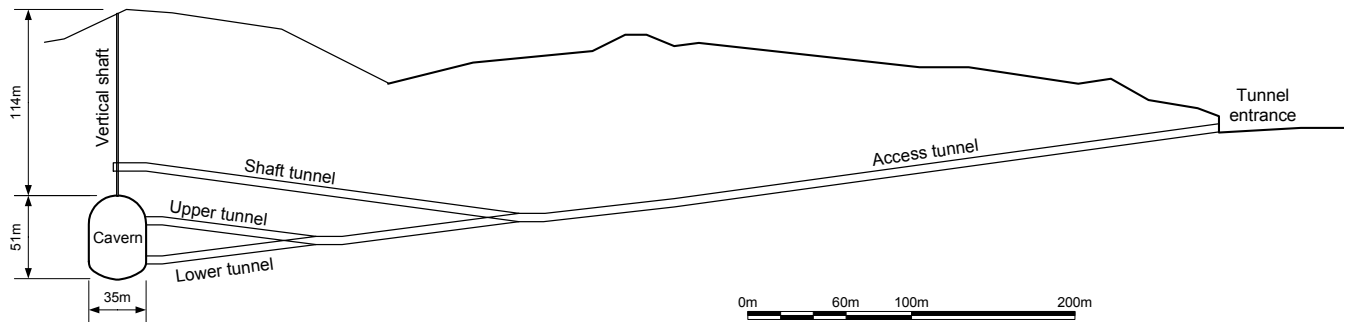


Figure 5. Layout of storage cavern and access tunnels at the LRC Demo Plant

The shape of the storage cavern is a vertical cylinder with a spherical top and rounded bottom, see Figure 6. The diameter is 36 meters and the height is 52 meters. The top of the cavern is at a depth of 115 meters below the ground surface. The geometrical volume is 40.000 cubic meters, which means that 10 million cubic meters of natural gas can be stored at the maximum pressure of 200 bar.

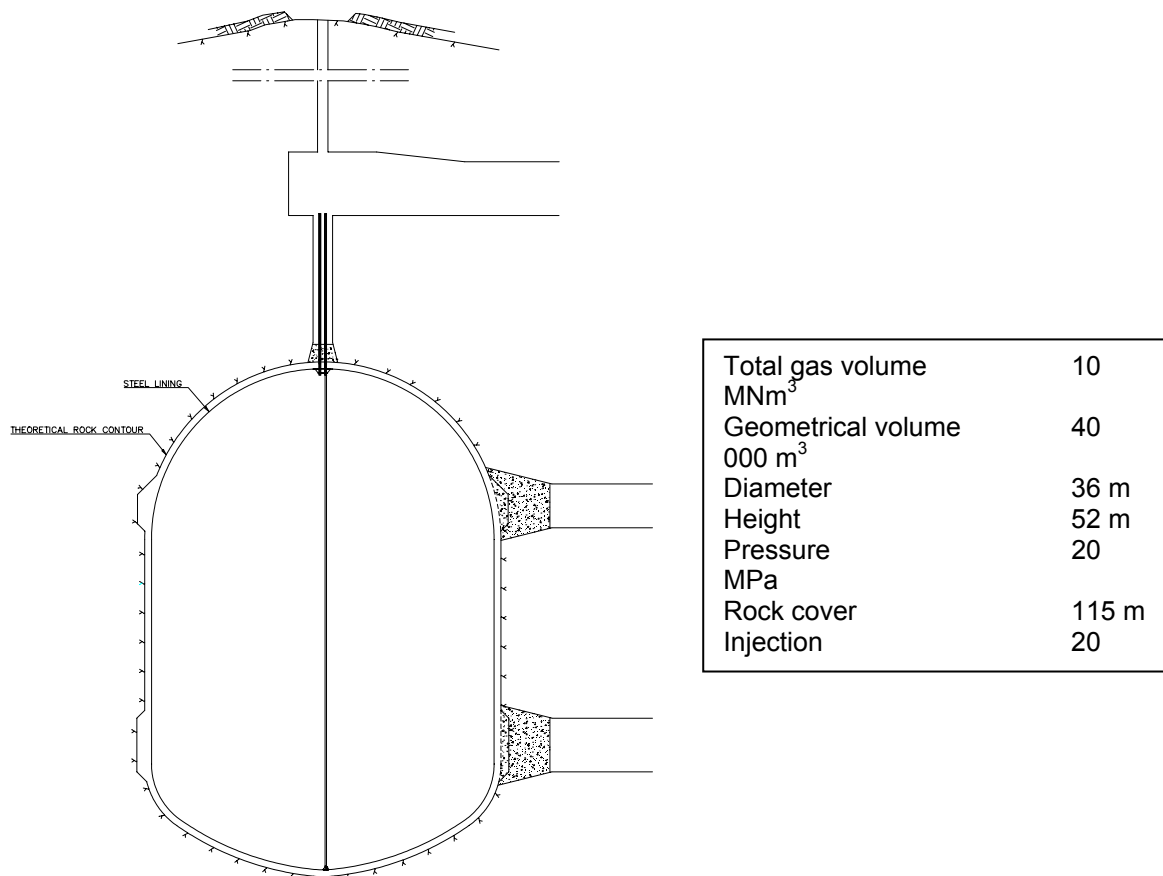


Figure 6. Vertical section of the LRC Demo Plant Cavern

The construction of the below ground facility started with the excavation of the access tunnels. The rock mass consists of a good quality gneiss. The cupola shaped upper part of the cavern was excavated first, followed by the bottom part. The rock volume in the cylindrical middle part was

excavated last. Smooth-blasting technique was used to create a rock surface suitable for the subsequent installation of the lining. The drainage system pipes were installed on the rock wall immediately after excavation and covered with a protective layer of shotcrete.

After the cavern was excavated, the steel lining was erected as a freestanding tank. The lining was welded together from large pre-formed steel plates of ductile carbon steel with a thickness of about 12 mm. Very high quality demands were put on the steel material and the welding procedures. 100% of the weld length was subjected to a non-destructive testing programme. All welding and inspection were carried out in the lower part of the cavern. Vertical jacks were used to successively lift the tank.

The last stage of the cavern construction was to fill the space between the steel lining and the rock with concrete. Self-compacting concrete was used, which meant that a high and uniform concrete quality could be achieved without the use of vibrating poker. Water was filled inside the steel tank to support the concrete pressure during pouring.

The storage cavern is connected to the above ground facility via a drilled vertical shaft. The shaft contains pipes for injection and withdrawal of gas. The gas process equipment in the above ground facility is similar to that of salt cavern storage.

The LRC Demo Plant can be operated from the control room in the above ground facility. However, after an initial operational period, the LRC Demo Plant will normally be remotely operated from the central gas grid control room in Malmö.

The construction of the LRC Demo Plant was finished in the summer of 2002. After that, an extensive scientific testing programme started, including loading of the cavern up to 220 bar and multiple load cycles. The behaviour of the rock and the lining was monitored by a comprehensive measurement system. The preliminary evaluation of the mechanical behaviour of the rock mass and the cavern wall indicates that the deformation level in general is slightly less than expected and thus well below the design limits.

Commercial operation of the LRC Demo Plant will start during year 2003.

6. CONCLUSIONS

The construction of the LRC Demo Plant was the final step of a long development process that started 20 years ago. The storage will improve the reliability and the deliverability in the Swedish gas grid. In a wider perspective, the Demo Plant has finally lifted the LRC technology from the development phase. The LRC concept has emerged as an existing commercial technology and is now ready to challenge other existing storage alternatives on the market. The international interest in the LRC concept is great, for instance in North America, Japan and the Far East.

The main advantages of the LRC technology are:

- Great freedom of localisation with respect to geology
- High deliverability and turnover rates
- Low impact on landscape and environment
- No need for gas treatment
- Possibility to expand a storage plant in steps by adding storage cavern modules.