Snowmass2021 - Letter of Interest

Solution-mined salt caverns as sites for underground physics experiments

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Abstract: The oil and gas storage industry has very well-developed technologies for creating huge caverns in salt formations by a process called *solution mining*. The resulting spaces are huge (as large as $2 \times 10^6 \mathrm{m}^3$), inexpensive ($\mathcal{O}(\$20)/\mathrm{m}^3$), deep (1–3 km), and naturally low in U/Th. It may be possible to install and operate future underground experiments in these caverns, without conventional mining. Detector-engineering challenges, like those of deploying a large apparatus down a narrow wellbore, appear solvable in principle. For one example, large scintillator and water Cherenkov experiments could be built out of KM3NeT-like DOM strings. For another example, the caverns could serve as pressure vessels for high-pressure TPCs of otherwise-impossible sizes. If successful, experiments like these would be operated from the surface with few of the operating costs and mine-specific safety issues of conventional underground labs. To make progress, we need involvement from both drilling experts and physicists. There may be an opportunity to start by building a small facility we call CUSO in Cleveland, Ohio.

Solution-mined salt caverns for underground physics

The oil and gas industry uses giant caverns in geological salt formations to store pressurized natural gas and liquid petrochemicals. The "solution mining" process is quick and inexpensive; the geological formations needed are widespread; and the resulting caverns are of the sizes and depths associated with deep underground experiments. In this letter, we express our view that solution-mined caverns are an untapped opportunity which the underground-physics community could exploit.

Solution mining as a means of obtaining salt is hundreds of years old, but caverns emerged as important storage vessels in the 1960s[1]. The process begins by drilling a well into the target salt formation, then lowering a tubing string down its center. Fresh water, pumped down one tube, forms a cavity by dissolving away salt. Salt-saturated brine is forced up and is sold, discarded, or desalted and reused. By manipulating the depth of the injection string and other factors, like cover fluids, we can leave the dissolved cavity in any desired rough shape and size; in salt domes the typical choice is a cylinder 60–80 m diameter and over 500 m tall ($1\text{–}2\times10^6\,\mathrm{m}^3$). These caverns' long-term stability is well understood.

Underground physics experiments (neutrinos, dark matter, rare decays) need large underground spaces, both for increasingly massive targets and for thicker shielding/veto systems. Could we use solution-mined caverns instead of conventional mined labs[2]? Among the advantages:

- **Cost saving** Creating a salt cavern (\$20/m^3) rather than a new hard-rock excavation (\$1000/m^3) might make a medium-to-large project cost effective. A cavern and its surface infrastructure may have far lower operating costs than an occupied underground lab.
- **High-pressure gas targets** With the whole cavern as a pressure vessel, high-pressure gas—known to be a useful detector medium, with distinct advantages over liquid cryogens[3]—can be used at scales (see Table 1) impossible elsewhere.
- **Safe use of hazardous gases** A salt cavern can be a safe place to deploy useful-but-hazardous materials (CS_2, H_2, CH_4, radioactive sources) which might not be permitted in a mine at all.
- **Site flexibility** Since bedded salt formations are numerous and extensive, a solution-mining drill pad can be sited more flexibly than a mine; we might, e.g., place a new detector cavern near a nuclear reactor site or off-axis from a neutrino beam.

The question for the physics community is: *how* is it possible to use these caverns? What kind of detector could ever go there? The most daunting engineering constraint is the narrow remote access. Humans and human-operated equipment will stay on the surface; we *probably* must lower our detector, whether piecemeal or all at once, down a narrow well (30-100 cm is familiar to drillers and regulatory agencies; larger shafts would require study). In the cavern, high pressures (≈100 bar/km) are typical, but sometimes avoidable. However, it seems possible to design detectors that fit:

- **Inflatable time projection chambers** Time projection chambers with spherical[4] or cylindrical drift are interesting because their delicate, segmented, electrically-instrumented anode may be small enough to fit down the well in one piece; the larger gas-filled drift volume, and the cathode that surrounds it, might be made *inflatable*. A large cylindrical TPC might consist of a (say) 10 m diameter, 100 m tall metallized cathode balloon, which can hang vertically with a 50 cm anode cylinder dangling in its center; it fits down a wellbore when deflated, and inflates in the cavern.
- **DOM-based water Cerenkov or scintillator detectors** The pressure-housed PMT modules used in experiments like IceCube and KM3NeT provide many of the technologies need to build HyperK/THEIA-like detectors under pressure. A thin balloon would line the cavern so that the interior could be filled

Target	Goals	Density	Cavern size			Compare to ...
		(kg/m^3)	small	medium	large	
H_2	Light dark matter, anti-ν	4–7	2 T	500 T	60 kT	1 kg NEWS-G
CH_4	reactor-/geo-neutrino	270–450	140 T	30 kT	4 MT	20 kT JUNO
Ne	dark matter, solar neutrino	50–80	30 T	6 kT	700 kT	20 T CLEAN
Ar	Atm/accel ν, proton decay	100–170	50 T	12 kT	1.5 MT	40 kT DUNE
Xe	dark matter, $0\nu\beta\beta$	580–960	300 T	70 kT	8 MT	7 T LZ
CF_4	Directional dark matter (75 torr)	0.4	200 kg	30 T	3 kT	4 kg DRIFT-III
H_2O	Atm/accel ν, proton decay	1000	500 T	70 kT	7 MT	1 MT Hyper-K

Table 1: The physical scales of salt caverns, translated into detector masses at room temperature and the listed pressures. We show the detector mass (leaving aside feasibility issues like Xe availability, instrument cost, etc.) that fits into: a small Salina salt cavern like CUSO (10 m diameter at 60 bar), a larger but still bedded-salt-compatible medium cavern (7×10^4 m^3, 100 bar), or a very large domal cavern like Bayou Choctaw 102 (2×10^6 m^3, 100 bar). Gas TPCs, which in a conventional lab are pressure-vessel-limited, can expand to huge sizes. Caverns can in principle support underpressure, allowing low-pressure TPCs to expand to ton-scale. Proton-rich but flammable target gases like H_2 and CH_4 can be used safely.

with fresh water rather than brine. Buoyant strings would be dropped into the cavern and, with the aid of an in-cavern ROV[5] or manipulator, parked in an inward-facing cylindrical array, with some string-string interconnection to maintain alignment.

- **One-piece experiments using caverns for shielding** Some experiments consist of a small, one-piece core that fits down a wellbore. We might use a salt cavern to house an unusually-large shielding/veto pool into which such an apparatus can be lowered and retrieved.

Starting where we are today, how can we move forward towards launching salt-cavern-based detector projects? One possibility for the next step is to spark a conversation across several DOE divisions; while the detector and physics case will come from the Office of Science or NNSA, the DOE Office of Fossil Energy is the owner/operator of numerous caverns at its four Strategic Petroleum Reserve sites; several DOE labs, particularly Sandia but also NETL, have expertise in salt caverns for fossil fuel, hydrogen, compressed air, and nuclear waste storage uses. In the UK, Boulby Lab's research portfolio includes solution mining for energy storage. Worldwide and nationwide, though, the vast majority of drilling and solution-mining expertise is in industry rather than government/academia. The author gave a talk[6] at the Solution Mining Research Institute technical conference in 2016; at least at this level the drilling/cavern-expert feasibility feedback was encouraging.

On the physics side, it is important to engage more physicists in the process of detector brainstorming and problem-solving towards dark-matter, $0\nu\beta\beta$, proton decay, reactor monitoring, or other goals. Our most-detailed design and simulation work to date has been on a concept for a 500T neon TPC for solar neutrinos[7], but it is clear that very-low-hanging fruit remains unpicked.

On the hands-on side, at Case Western Reserve University, we are considering a prototype-scale facility called the Case Underground Salt Observatory (CUSO). The campus lies 600 m above the well-characterized 'Salina' salt bed, best known among physicists for having hosted the IMB experiment. We propose to solution-mine the 23 m thick F1 Salina sublayer and obtain a 15 m spherical cavity with a 10-12" well. A CUSO R&D program would be able to test cavern lining and downhole gas handling methods; measure backgrounds; and conduct a physics program with new light-dark-matter sensitivity using ton-scale H_2/He TPCs.

References

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