Snowmass2021 - Letter of Interest

Solution-mined salt caverns for underground physics

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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 use these spaces for future underground experiments, without conventional mining. Detector-engineering challenges, like those of deploying a large apparatus down a narrow wellbore, appear solvable in principle; for example, large scintillator and water Cherenkov experiments could be built out of KM3NeT-like DOM strings. Moreover, salt caverns offer unmatchable opportunities for scaling-up high pressure TPCs. 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 salt caverns are an untapped opportunity for future underground experiments.

"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 two nested tubes down its center. Fresh water, pumped down the inner tube, forms a cavity by dissolving away salt. Salt-saturated brine is forced up and is sold, discarded, or recycled. By manipulating the depth of the injection pipe 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 (1–2$\times 10^6$m^3)

Can we use these caverns, instead of conventional underground labs, as underground sites for physics experiments[2]? Different advantages might arise in different cases:

- **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.
- **Safe use of hazardous gases** A salt cavern can 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.
- **High-pressure gas targets** With the whole cavern as a pressure vessel, high-pressure gas TPCs and other dense gaseous detectors[3] are possible at scales (see Table 1) impossible elsewhere.
- **Site flexibility** A solution-mining drill pad can be sited more flexibly than a mine; we might, e.g., place a new detector cavern a freely-chosen distance from a reactor, or position 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 must lower our detector, whether piecemeal or all at once, down a narrow well. While 20-30cm casings are more common, 1m well drilling is possible. (In mining contexts, large shafts can be blind-drilled at 3–5 m, but this is outside any salt-solutioning experience.) We have three conceptual pictures of salt-cavern-compatible detectors (of course this does not exhaust the possibilities)

- **Inflatable time projection chambers** Time projection chambers with spherical or cylindrical drift are interesting because their delicate, segmented, electrically-instrumented anode may be small enough to fit down the well in one piece, while the larger gas-filled drift volume, and the cathode that surrounds it, might be made *inflatable*. A large cylindrical TPC migh 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.[4].
- **DOM-based water Cerenkov detectors** Experiments like IceCube and KM3NeT showed that pressure-tolerant PMT modules cost little more than conventional PMTs, making it possible to build HyperK/THEIA-like detectors in situ. A thin balloon would line the cavern so that the interior could be filled with fresh water rather than brine. Buoyant strings would be dropped into the cavern and parked in an inward-facing cylindrical array, with some string-string interconnection to maintain alignment. This might

Target	Goals	Density		Mass		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
He	Light dark matter search	9–15	5 T	1.1 kT	130 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	0.2 T	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 ($7 \times 10^4 m^3$, 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 or cryostat-limited, could expand to huge sizes. Caverns could 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 at scale.

require a submarine in the cavern, which has been done before[5].

- **One-piece experiments using caverns for shielding** Some experiments consist of a small, one-piece core that fits down a wellbore. Given a cavern that tolerates ambient pressure, something the size of the LUX vacuum vessel might be lowered and immersed in a very large shielding/veto pool.

Starting where we are today, how can we move forward to designing, proposing, and building salt-cavern-based detectors and salt-caverns in the future? We start with a chicken/egg problem. Do we need drilling-industry design studies in hand before particle physicists can justify working on detector designs? Or should a more-detailed physics case be in place first, to justify the drilling/cavern engineering work? What is the relative value of large-detector sensitivity studies vs. getting hands-on down-well experience from small detectors? As a first step towards resolving this, the author gave a talk[6] at the Solution Mining Research Institute[7] technical conference in 2016 and, at least at this level, the drilling/cavern-expert feasibility feedback was positive. One possibility for the next step is to spark a conversation across DOE divisions. The Office of Fossil Energy is the owner/operator of numerous caverns at its four Strategic Petroleum Reserve[8] 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; physics and detector engineering comes from the Office of Science and NNSA. Worldwide and nationwide, though, the vast majority of drilling and solution-mining expertise is in industry rather than government/academia.

At Case Western Reserve University, we have identified a route to a prototype-scale facility called the Case Underground Salt Observatory (CUSO). The campus lies 600 m above a 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.

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