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URL Cost and Design Considerations

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Generic and Site Specific Underground Research Laboratories to Support Siting, Design and Safety Assessment Developments

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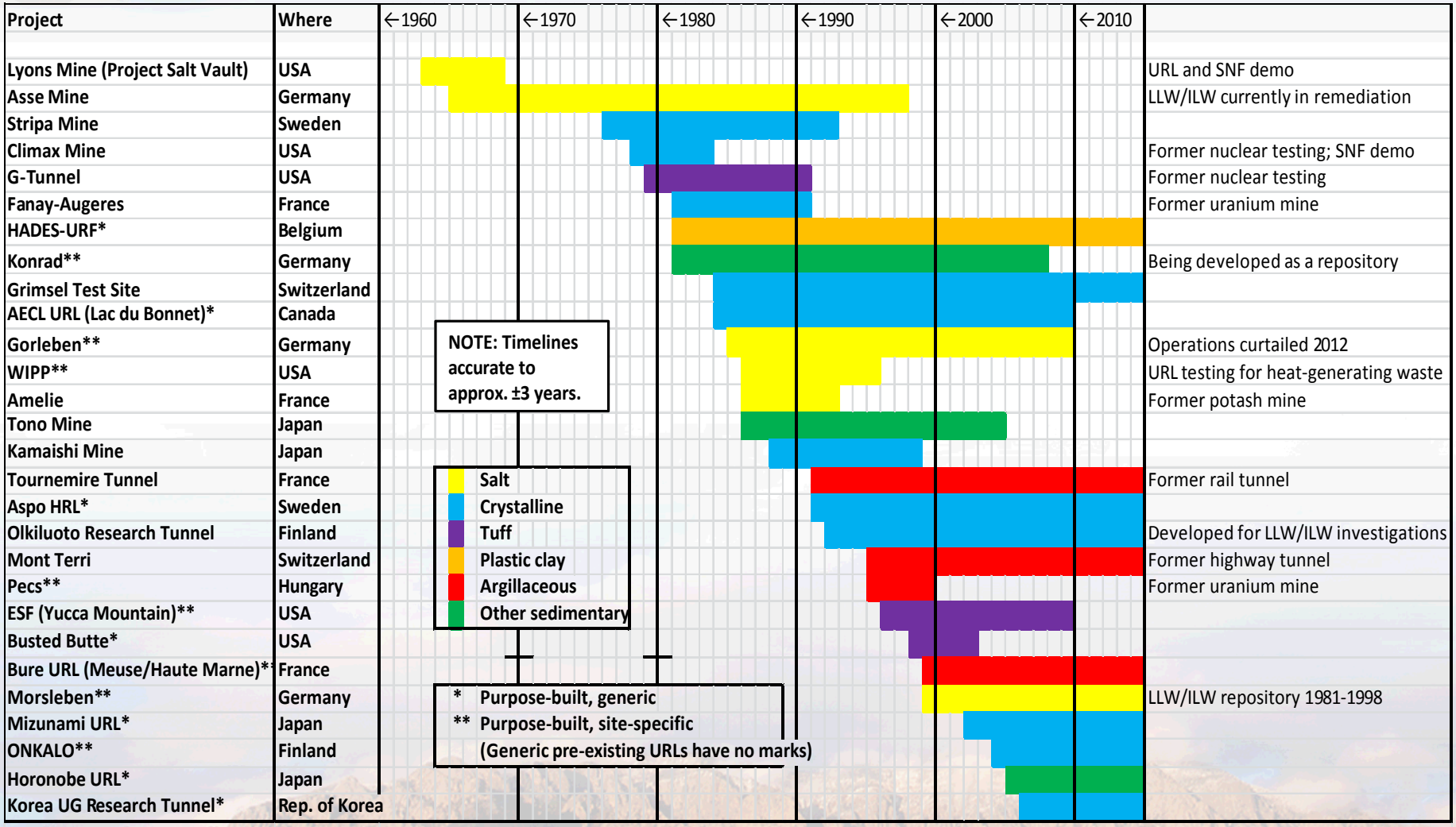
URL Cost and Design Considerations
Outline

- Background on URL Development
- Examples
  - Early URLs (Salt Vault, SFT-Climax, Stripa)
  - U.S. URLs (WIPP, Yucca Mountain ESF)
  - International Example URLs (Äspö, Mont Terri, Bure, ONKALO)
- Exercise #1
- Exercise #2
- Planning Considerations
- Physical/chemical/biological science URLs
- Summary

Worldwide URL Summary - Timelines



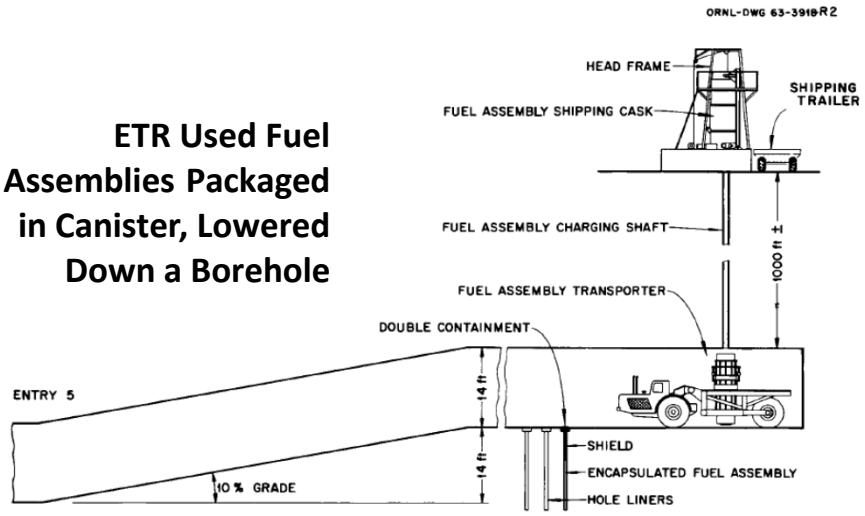
Project	Where	
Lyons Mine (Project Salt Vault)	USA	URL and SNF demo
Asse Mine	Germany	LLW/ILW currently in remediation
Stripa Mine	Sweden	
Climax Mine	USA	Former nuclear testing; SNF demo
G-Tunnel	USA	Former nuclear testing
Fanay-Augeres	France	Former uranium mine
HADES-URF*	Belgium	
Konrad**	Germany	Being developed as a repository
Grimsel Test Site	Switzerland	
AECL URL (Lac du Bonnet)*	Canada	
Gorleben**	Germany	Operations curtailed 2012
WIPP**	USA	URL testing for heat-generating waste
Amelie	France	Former potash mine
Tono Mine	Japan	
Kamaishi Mine	Japan	
Tournemire Tunnel	France	Former rail tunnel
Aspo HRL*	Sweden	
Olkiluoto Research Tunnel	Finland	Developed for LLW/ILW investigations
Mont Terri	Switzerland	Former highway tunnel
Pecs**	Hungary	Former uranium mine
ESF (Yucca Mountain)**	USA	
Busted Butte*	USA	
Bure URL (Meuse/Haute Marne)**	France	
Morsleben**	Germany	LLW/ILW repository 1981-1998
Mizunami URL*	Japan	
ONKALO**	Finland	
Horonobe URL*	Japan	
Korea UG Research Tunnel*	Rep. of Korea	

NOT SHOWN: Early U.S. URLs (Avery Island, CSM Mine, etc.) and recent URL developments in the Czech Republic, Canada, and China.

Salt Vault: URL and Demonstration 1963-1968

- Former Lyons Salt Mine
- 14 Test-Reactor Fuel Assemblies Contained in 7 Canisters
- Waste Packaging
- Waste Handling Borehole and Underground Transporter
- Thermomechanical Salt Responses
- Laboratory Core Testing and Model-Pillar Studies
- Numerical TM Simulation
- Scaled-up HLW Disposal Concept
- Total Multi-year Cost ~$10M ($50M to $100M escalated)

ETR Used Fuel Assemblies Packaged in Canister, Lowered Down a Borehole



Bradshaw, R.L and W.C. McClain 1971. ***Project Salt Vault: A Demonstration of the Disposal of High-Activity Solidified Wastes in Underground Salt Mines*****. Oak Ridge National Laboratory, ORNL-4555.**

Spent Fuel Test – Climax: 1978-1985

- **Test Development: $18.5M**
  - ~420 m depth, Climax granite stock, Nevada Test Site
  - Demonstration:
    - Construction (surface and U/G)
    - Waste transport & handling
    - Spent fuel packaging and emplacement
    - Retrieval
  - 12 PWR assemblies, Turkey Point NPP (one per canister)
- **Total Project Cost: $34M ($90M to $130M escalated)**

Rail-mounted canister transfer and emplacement machine, main gallery (in receive position under waste handling borehole)

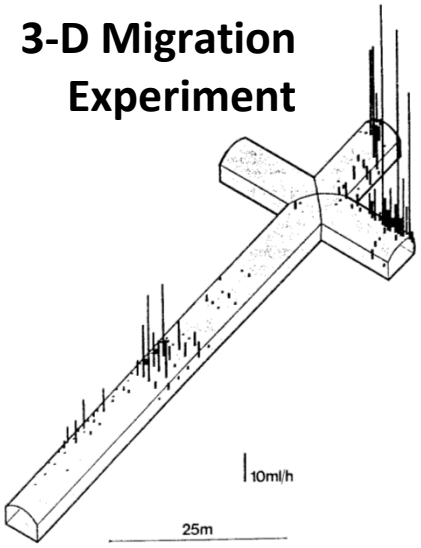
Patrick, W.C. 1986. *Spent Fuel Test—Climax: An Evaluation of the Technical Feasibility of Geologic Storage of Spent Nuclear Fuel in Granite (Final Report).* Lawrence Livermore National Laboratory, Livermore, CA. UCRL-53702.

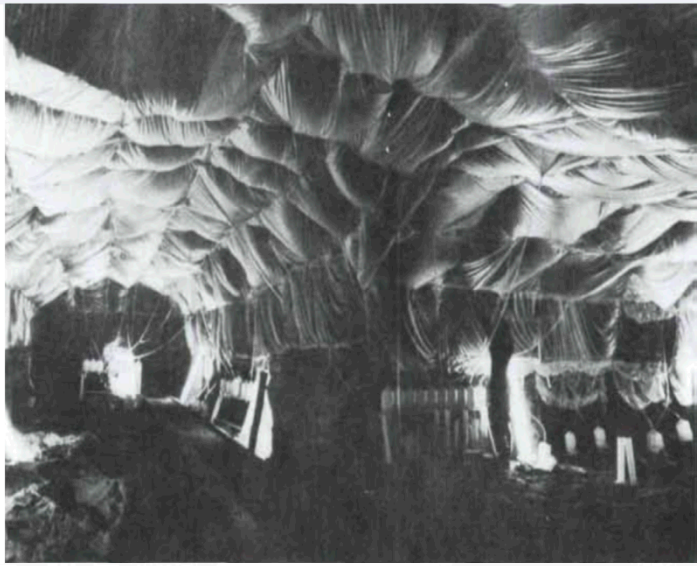
The Stripa Project: 1980-1992 (Generic URL)

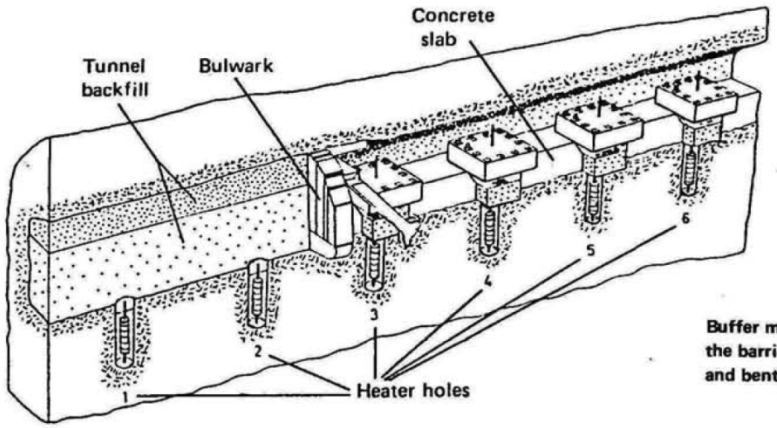
- Swedish-American Cooperative → OECD/NEA Project
- Canada, Finland, Sweden, Switzerland & USA
- Granite depth 300 to 400 m
- Many experiments; 170 reports
- Total cost ~$33M ($60M to $80M escalated)

Phase	Period	Budget
1	1980 - 1985	47 MSEK
2	1983 - 1988	66 MSEK
3	1986 - 1992	144 MSEK

3-D Migration Experiment







Buffer Mass Test

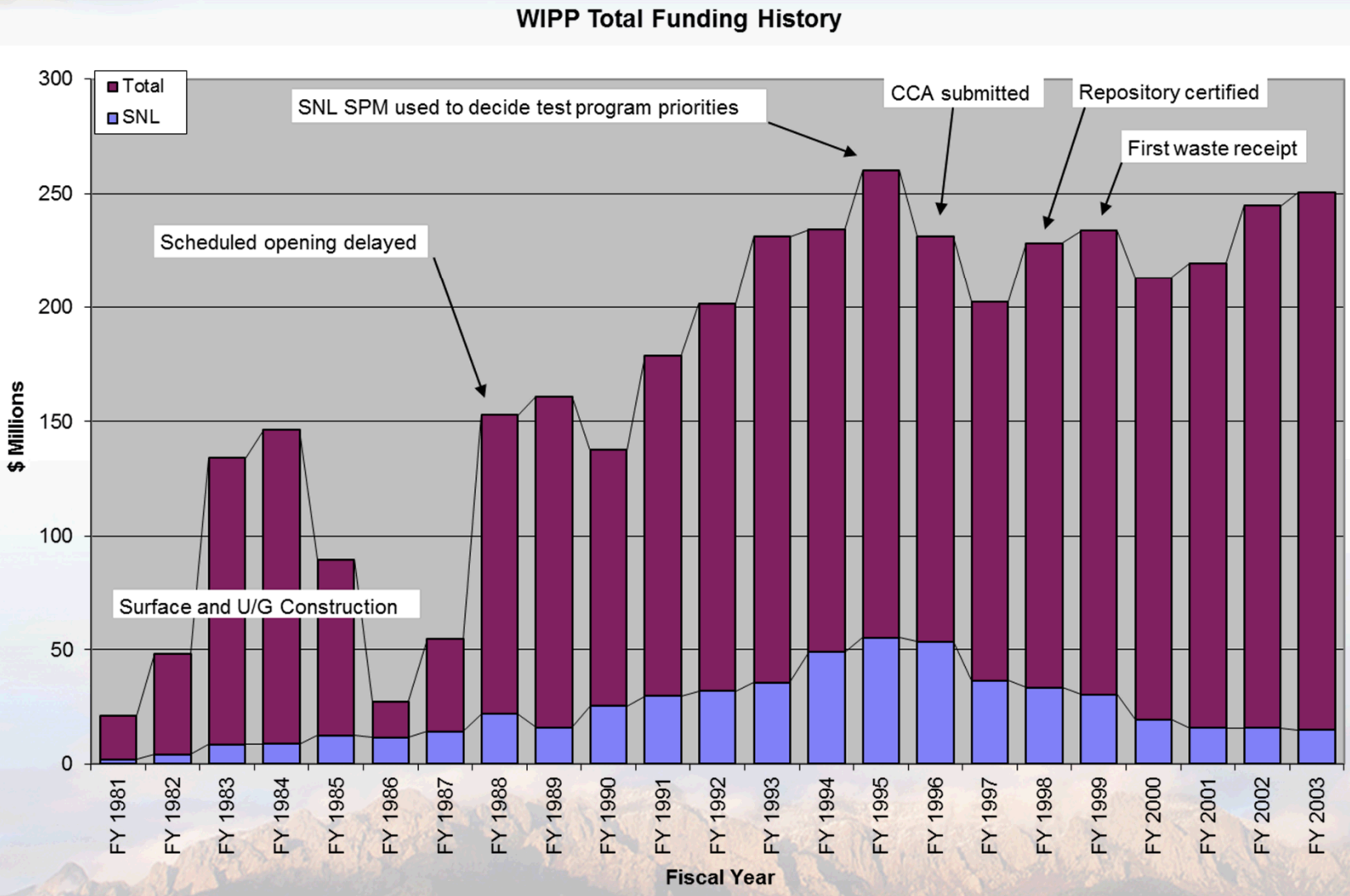
Buffer mass tests were done to verify the barrier function of bentonite and bentonite/clay mixtures.

Fairhurst, C., G. Ferruccio, P. Gnirk, M. Gray and B. Stillborg 1993. *OECD/NEA International Stripa Project 1980–1992: Overview Volume I – Executive Summary*. (http://www.skb.se/Templates/Standard_17139.aspx)

WIPP URL (Historical)

- Operated by the U.S. DOE for R&D during 1986–1996
- Shafts descend ~600 m
- R&D conducted by Sandia and supporting researchers
- Construction cost ~$200M (w/out repository facilities)
- Total URL operating cost ~$200M (15% of WIPP budget)
- URL experiment cost: ~$80M (50% of Sandia total)
  - As many as 50 technical workers for 10 years

Yucca Mountain Exploratory Studies Facility



Yucca Mountain Exploratory Studies Facility

YM ESF Test	Total Cost	Cost Basis
Single Heater Test (2 yr)	$5M	Construction, Drilling: $1M Procurement, Design, Install, Baseline: $3M Annual Operation: $1M
Drift Scale Test (8 yr)	$59M	Construction, Drilling: $8M Procurement, Design, Install, Baseline: $11M Annual Operation: $5M
Other Tests	~$60M	Roughly equivalent to heated tests
Testing Support (1996 – 2007)	$50M	Annual Test Operations Support: ~$5M
ESF Construction & Operation	$240M	Surface and U/G Construction: ~$120M Annual Operation: ~$20M

Drift Scale Test (9 simulated packages; >200 kW)

Aerial view of ESF surface facilities; north and south portals

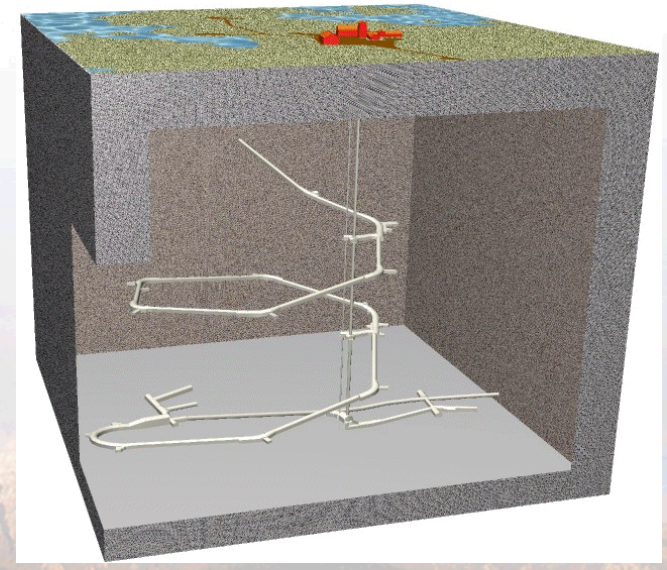
Yucca Mountain ESF Design Considerations

- **Purpose built, site-specific URL**
- **Main tunnels to be part of repository →**
  - **Regulatory reviews**
  - **Quality assurance**
  - **Administrative controls (e.g., materials review and inventory)**

- **Characterization studies:**
  - **Test construction methods (e.g., dry drilling)**
  - **Hydrologic studies → Water inventory and use of chemical tracers**
  - **Chemical/isotopic studies → Tracer purity and concentration**

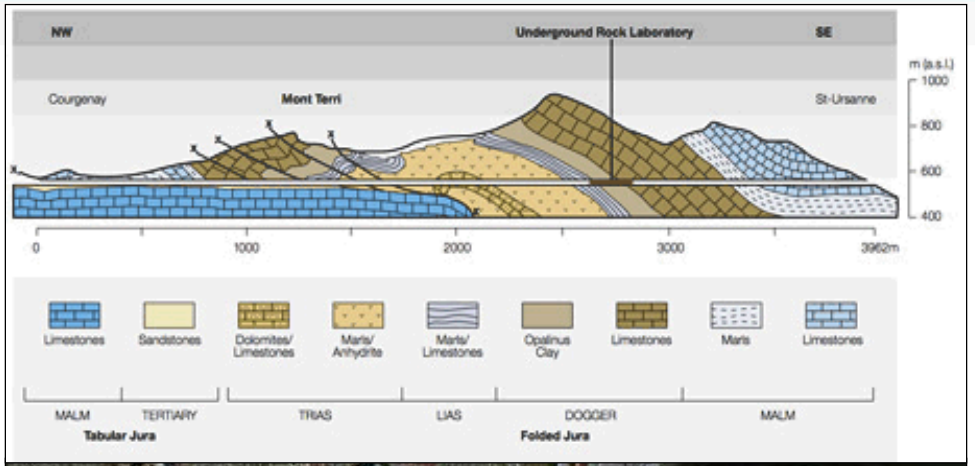
Äspö Hard Rock Laboratory, Sweden

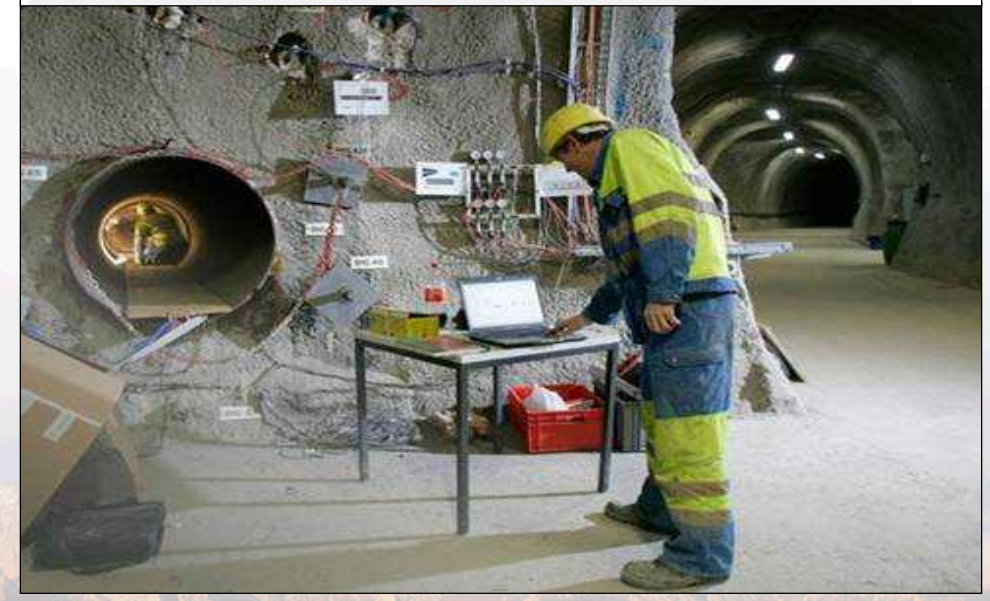
- Operated by SKB since 1991
- Ramp descends 460 m (3.6 km)
- Participants have included Canada, Finland, France, Japan, Switzerland, UK, and USA
- Cumulative operating cost ~$50M
  - Average ~$3M/year
- Experiment cost ~$50M
  - Contributions from international participants
  - ~50 experiments
- Staffing
  - 55 staff members, 45 consultants, 25 external project managers



Mont Terri URL, Switzerland

- Operated by Swisstopo (and predecessor) since 1996
- Host medium: Opalinus Clay
- General+operating cost ~$16M through 2015
  - Average ~$800k/year
- Experiment cost ~$83M
  - Contributions from international participants
  - >70 experiments total
  - Average ~$4M/year (not including science support)
- Discussion?
  - Staffing? Other costs?
  - Funding-imposed limits?





Mont Terri URL – Annual Cost Summary

(http://www.mont-terri.ch/internet/mont-terri/en/home/project/funding.html)

Annual investment 1996 bis 2015

Experiment costs

	1996 Phase 1 (effective)	1996-1997 Phase 2 (effective)	1997-1998 Phase 3 (effective)	1998-1999 Phase 4 (effective)	1999-2000 Phase 5 (effective)	2000-2001 Phase 6 (effective)	2001-2002 Phase 7 (effective)	2002-2003 Phase 8 (effective)	2003-2004 Phase 9 (effective)	2004-2005 Phase 10 (effective)	2005-2006 Phase 11 (effective)	2006-2007 Phase 12 (effective)	2007-2008 Phase 13 (effective)	2008-2009 Phase 14 (effective)	2009-2010 Phase 15 (effective)	2010-2011 Phase 16 (effective)	2011-2012 Phase 17 (effective)	2012-2013 Phase 18 (effective)	2013-2014 Phase 19 (budget)	2014-2015 Phase 20 (budget)	1996-2015 Total
ANDRA	301'716	593'373	1'421'639	1'503'676	397'396	106'222	187'803	109'367	2'487'697	749'777	517'553	397'616	736'148	1'747'987	353'268	319'086	279'603	259'255	179'833	196'307	12'915'323
ANDRA (Forpro)	0	0	0	0	0	0	0	0	0	0	0	146'145	205'635	95'385	0	0	0	0	0	0	447'165
BGR	0	46'785	75'764	79'693	198'809	400'792	262'586	217'554	535'098	387'315	555'297	408'419	299'728	449'152	337'089	194'932	143'822	210'491	420'250	287'990	5'511'566
CHEVRON	0	0	0	0	0	0	0	0	0	0	0	0	0	0	313'147	162'298	132'668	269'740	450'000	70'094	1'397'947
CRIEPI	0	0	0	0	0	0	0	148'325	167'280	195'288	227'236	201'116	222'524	218'028	52'787	79'690	55'968	30'238	27'000	28'200	1'653'680
DOE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	102'249	168'333	163'333	433'915
ENRESA	0	40'445	1'119'514	1'022'627	230'986	377'116	323'702	182'181	358'692	173'556	43'385	72'049	48'851	10'676	10'136	73'238	3'750	18'500	12'500	47'000	4'168'905
FOWG/swisstopo	0	0	0	0	0	0	13'195	46'950	66'698	19'178	0	42'752	80'483	473'738	85'412	97'691	145'166	270'033	276'750	371'500	1'989'547
GRS	0	0	0	183'937	168'666	158'348	28'272	21'365	378'371	303'238	85'500	113'739	165'641	246'233	95'911	73'950	95'744	154'520	91'000	132'649	2'497'084
ENSI (HSK)	0	0	0	0	0	0	0	0	137'195	201'409	48'320	34'878	17'636	565'424	123'003	94'934	71'116	132'223	76'250	112'000	1'614'388
IRSN	0	42'459	111'045	104'368	103'334	92'253	89'988	103'971	61'396	52'132	108'160	45'959	34'294	100'345	136'710	86'553	49'265	83'449	99'500	56'506	1'561'687
JAEA	69'316	45'621	137'823	116'849	131'688	113'059	42'233	32'992	43'836	21'597	36'336	20'759	59'009	22'730	3'214	3'226	6'144	7'071	5'750	24'500	943'552
NAGRA	301'716	408'285	1'230'370	692'167	527'773	487'585	322'529	299'293	1'019'205	2'141'772	943'402	626'927	1'666'748	2'835'983	1'003'187	3'856'005	956'141	1'026'002	1'629'167	815'823	22'787'876
Obayashi	0	51'299	92'388	77'529	57'741	98'275	77'449	41'615	60'532	60'945	44'358	62'046	72'050	53'646	49'793	28'232	36'131	37'821	36'000	28'200	1'066'049
SCK•CEN	122'841	79'474	204'748	187'431	127'625	63'760	45'452	30'761	39'836	43'453	50'635	62'082	54'262	58'059	70'603	57'991	76'118	80'031	58'500	58'200	1'571'862
NWMO	0	0	0	0	0	0	0	0	0	0	0	0	0	186'525	199'439	135'237	169'091	231'703	241'667	201'423	1'365'085
TOTAL EXPERIMENT COSTS	795'589	1'305'741	4'463'092	3'968'279	1'944'018	1'897'410	1'393'208	1'234'375	5'355'835	4'349'661	2'660'182	2'234'487	3'663'008	7'063'911	2'833'699	5'263'063	2'220'727	2'913'326	3'772'500	2'593'525	61'925'636

General costs

Only totals per Phase are giv

	1996 Phase 1 (effective)	1996-1997 Phase 2 (effective)	1997-1998 Phase 3 (effective)	1998-1999 Phase 4 (effective)*	1999-2000 Phase 5 (effective)	2000-2001 Phase 6 (effective)	2001-2002 Phase 7 (effective)	2002-2003 Phase 8 (effective)	2003-2004 Phase 9 (effective)	2004-2005 Phase 10 (effective)	2005-2006 Phase 11 (effective)	2006-2007 Phase 12 (effective)	2007-2008 Phase 13 (budget)	2008-2009 Phase 14 (effective)	2009-2010 Phase 15 (effective)	2010-2011 Phase 16 (effective)	2011-2012 Phase 17 (effective)	2012-2013 Phase 18 (effective)	2013-2014 Phase 19 (budget)	2014-2015 Phase 20 (budget)	1996-2015 Total
Management and infrastructure	221'553	358'523	401'651	573'241	502'371	455'885	494'962	460'769	562'841	520'523	500'880	410'134	489'611	496'574	478'431	501'330	498'520	684'634	529'195	495'953	9'637'581
Unforeseen costs	62'421	65'859	174'860	489'100	44'188	10'448	26'110	0	32'921	21'752	24'434	20'416	8'523	34'604	25'101	28'779	24'236	34'366	26'460	24'798	1'177'376
TOTAL GENERAL COSTS	283'974	424'382	576'511	1'062'341	546'559	466'333	521'072	460'769	595'762	542'275	525'314	430'550	498'134	531'178	503'532	528'109	515'232	719'000	555'655	520'751	10'807'432

* Renovation of offices amounts to 283416 CHF and is included in the unforseen costs of Phase 4

Experiment+general costs, operational costs since Phase 12

	1996 Phase 1 (effective)	1996-1997 Phase 2 (effective)	1997-1998 Phase 3 (effective)	1998-1999 Phase 4 (effective)	1999-2000 Phase 5 (effective)	2000-2001 Phase 6 (effective)	2001-2002 Phase 7 (effective)	2002-2003 Phase 8 (effective)	2003-2004 Phase 9 (effective)	2004-2005 Phase 10 (effective)	2005-2006 Phase 11 (effective)	2006-2007 Phase 12 (effective)	2007-2008 Phase 13 (effective)	2008-2009 Phase 14 (effective)	2009-2010 Phase 15 (effective)	2010-2011 Phase 16 (effective)	2011-2012 Phase 17 (effective)	2012-2013 Phase 18 (effective)	2013-2014 Phase 19 (budget)	2014-2015 Phase 20 (budget)	1996-2015 Total
ANDRA	409'409	798'227	1'684'319	1'906'223	509'123	132'329	258'043	150'192	2'770'747	887'191	627'639	644'416	832'786	1'880'730	435'914	375'992	340'894	308'267	191'269	212'708	15'344'418
BGR	0	61'991	85'551	101'028	254'704	499'296	360'795	298'763	589'529	449'149	623'049	461'235	337'881	494'389	406'643	142'705	175'535	268'425	472'553	335'283	6'418'505
CHEVRON	0	0	0	0	0	0	0	0	0	0	0	0	0	0	367'810	179'670	155'354	333'873	504'121	85'094	1'625'922
CRIEPI	0	0	0	0	0	0	0	203'692	183'578	229'500	276'850	244'583	233'865	242'519	63'492	89'193	66'539	45'238	42'000	43'200	1'964'246
DOE											0	0	0	0	0	0	0	127'082	190'914	193'074	510'970
ENRESA	0	53'590	1'264'125	1'296'393	295'928	469'801	444'770	250186	393'191	200'236	54'505	85'597	53'284	12'808	13'640	8'889	11'365	33'500	27'500	62'000	5'031'308
FOWG/swisstopo	0	0	0	0	0	0	18'130	64476	72'967	24'106	2'036	53'331	86'792	474'106	111'825	108'910	169'826	308'144	305'199	425'498	2'225'147
swisstopo operator											0	500'000	500'000	500'000	427'350	301'762	257'756	303'429	386'535	401'441	3'274'844
GRS	0	0	0	233'179	216'086	197'266	38'846	29340	424'882	356'371	100'203	139'060	229'027	263'622	113'897	97'323	113'782	193'378	106'000	157'145	3'009'406
ENSI (HSK)	0	0	0	0	0	0	0	0	155'808	237'261	60'473	43'822	41'653	541'411	145'564	68'126	84'079	156'443	91'250	130'087	1'755'977
IRSN	0	56'259	125'389	132'308	132'386	114'926	123'644	142'782	68'734	62'652	132'842	57'204	36'234	113'762	175'390	115'968	56'438	98'449	114'500	71'506	1'931'373
JAEA	94'058	60'448	155'400	148'131	168'712	140'846	58'028	45307	47'832	26'335	45'980	28'591	55'981	30'108	8'475	6'619	8'381	22'071	20'750	39'500	1'211'553
NAGRA	409'409	538'332	1'389'301	877'466	676'156	607'420	443'158	411014	1'129'666	2'294'273	1'142'963	758'821	1'711'017	2'909'578	1'180'050	2'488'720	1'235'612	1'289'598	1'869'555	1'012'663	24'374'772
Obayashi	0	67'972	104'322	98'284	73'975	122'428	106'415	57149	68'517	72'961	56'682	76'632	83'261	58'338	59'992	32'059	43'569	52'821	51'000	43'200	1'328'577
SCK•CEN	166'687	105'304	231'196	237'608	163'507	79'431	62'451	42243	46'146	51'900	63'273	73'560	61'417	67'996	89'965	92'928	84'911	95'031	73'500	73'200	1'962'253
NWMO	0	0	0	0	0	0	0	0	0	0	0	0	0	208'727	237'829	157'603	197'196	282'008	268'144	230'136	1'579'843
TOTAL EXPERIMENT+OVER	1'079'563	1'730'123	5'039'603	5'030'620	2'490'577	2'363'743	1'914'280	1'695'144	5'951'597	4'891'935	3'185'495	3'166'852	4'263'198	7'796'094	3'837'636	4'266'467	3'001'237	3'614'328	4'714'690	3'515'735	73'548'918

*From Phase 12 on: rock laboratory operation budget of swisstopo

incl. contributions Galerie 08

Mont Terri URL Summary of Experiments

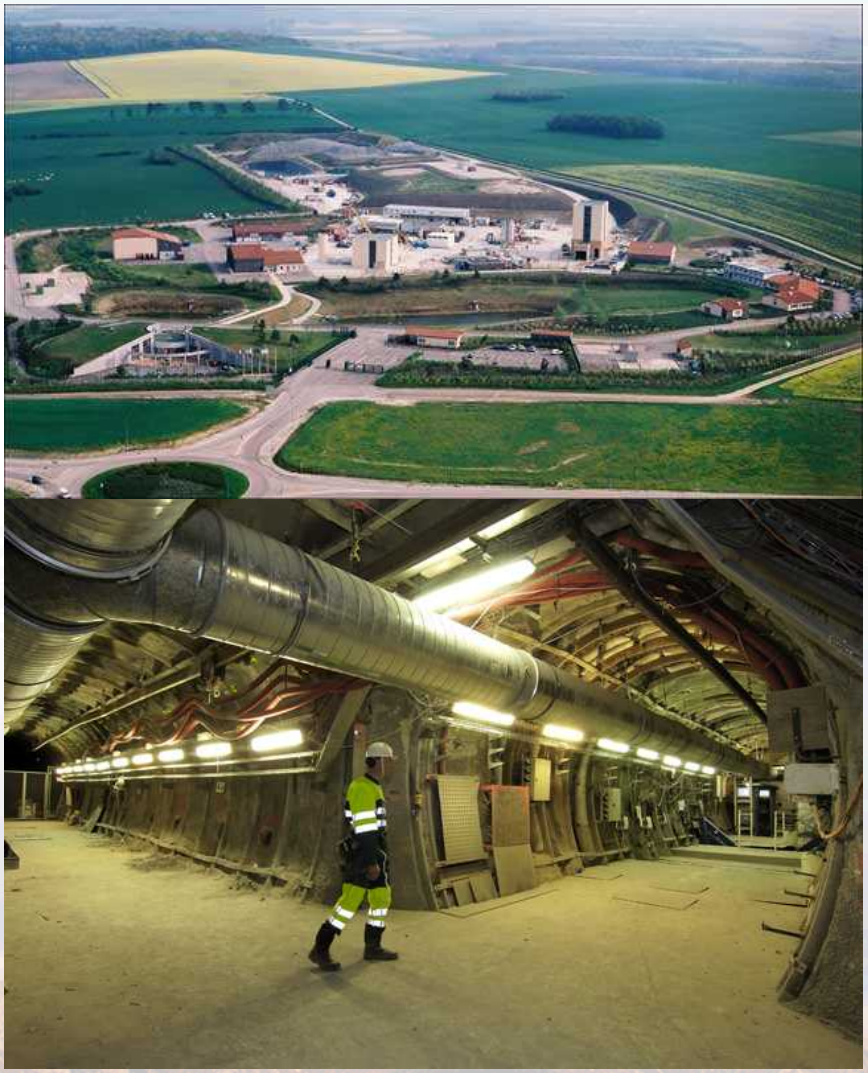
(http://www.mont-terri.ch/internet/mont-terri/en/home/experiments/list_of_experiments.html)

By topical area:
Drilling technique
Geochemical/microbiological
Diffusion
Hydrogeology
Gas migration
Rock mechanics
EDZ
THMC
Demonstration

Abbreviations	Experiments	2013 / 2014	Drilling technique	Geochemistry and microbiology	Diffusion	Hydrogeology	Gas Migration	Rock mechanics	EDZ (Excavation damage zone)	THMC (Thermo-hydro-mechanical-chemical characteristics)	Demonstration
AS	Anisotropy and rock stress							■			
BB	Borehole behaviour deformation								■		
BF	Borehole fluid effects					■					
BI	Borehole inventory										
BN	Bitumen-nitrate-clay interaction	■		■							
BW	Short term borehole wall development								■		
CD	Cyclic deformations	■				■		■			
CI	Cement-clay interaction	■		■							
CP	Chemical and physical weathering			■							
CW	High-ph cement porewater			■							
CS	Near well sealing integrity for CO2 geological storage	■					■				
DB	Deep inclined borehole through the Opalinus Clay	■				■					
DI	Diffusion experiment				■						
DM	Deformation mechanisms	■						■			
DR	Diffusion, retention and perturbations	■			■						
DS	Determination of stress							■			
DT	Drilling techniques		■								
EB	Engineered barriers										■
ED	EDZ (Excavation Damage Zone) research					■		■	■		
EG	EDZ gas diffusion be carbon isotope	■		■					■		
EH	EDZ self-healing								■		
EZ	EDZ fracture generation							■	■		
FE	Full scale emplacement demonstration	■									■
FI	Fluid-mineral interactions in OPA during natural faulting	■		■							
FM	Flow mechanisms & evaporation logging	■			■	■					
FP	Fracture propagation								■		
FS	In-situ clay faults slip hydro-mechanical characterisation	■				■		■			
GD	Analysis of geochemical data	■		■							
GM	Geochemical modelling and geophysical monitoring			■							
GP	Hydraulic and gas permeability					■	■				
GR	Ground penetration radar								■		
GS	Gasfrac self-sealing						■				
HA	Hydrgeological analyses	■				■	■				
HE	Heater experiment	■								■	
HG	Gas permeability and migration	■					■				
HM	Lab tests on HM coupled behaviour	■						■			
HT	Hydrogen transfer	■				■					
IC	Iron corrosion of Opalinus Clay	■		■							
IS	In situ stress							■			
LP	Long-term monitoring pore pressures	■				■					
LT	Laboratory temperature testing	■						■		■	
MA	Microbial activity	■		■							
MB	Mine-by Test							■			
MD	Cosmic muon density tomography	■									
MH	Long term monitoring of heaves	■						■			
MO	Monitoring	■									■
NT	Natural trace profil			■							
OP	Osmotic pore pressure measurements	■				■					
PC	Porewater chemistry	■		■							
PP	Porewater pressure					■					
PS	Petrofabric and strain determination	■						■			
RA	Rock mechanics analyses	■						■			
RB	Horizontal raise boring		■								
RC	Rock mass characterisation							■	■		
SB	Self-sealing barriers of clay-sand mixture	■					■				■
SE	Selfrac MT								■		
SF	Self-sealing of faults			■							
SM	High resolution seismic monitoring	■						■			
SO	Sedimentology of Opalinus Clay	■						■			
SR	Low pH shotcrete for rock support			■							
TH	Microscale THMC									■	
UZ	Unsaturated zone					■					
VA	Investigation of spatial variability within Opalinus Clay	■				■					
VE	Ventilation test					■	■				■
WS	Ground- and porewater sampling	■				■	■				■

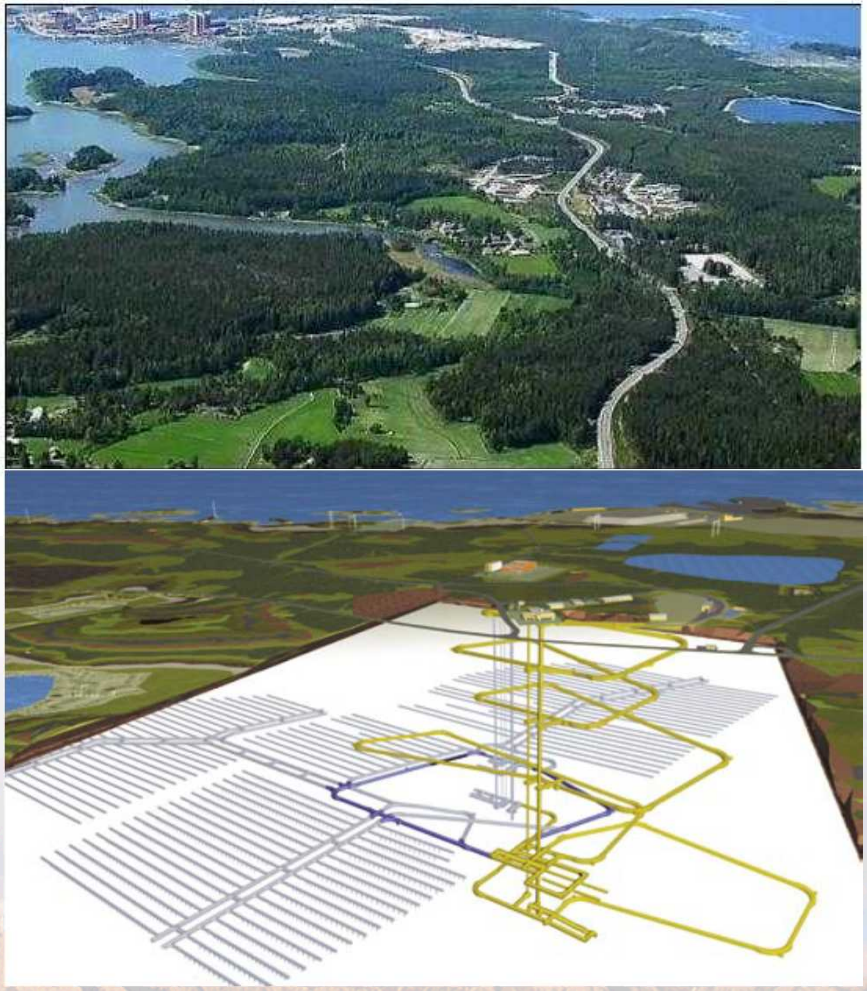
ANDRA URL at Bure, France

- Operated by ANDRA since 1999
- Hoste medium: COX argillite
- Shafts (2) descend 500 m
- Construction cost ~$380M through 2006
- $22M/year URL operating and experiment costs
- Operated by SKB since 1991
- International participation
- ~100 on-site employees

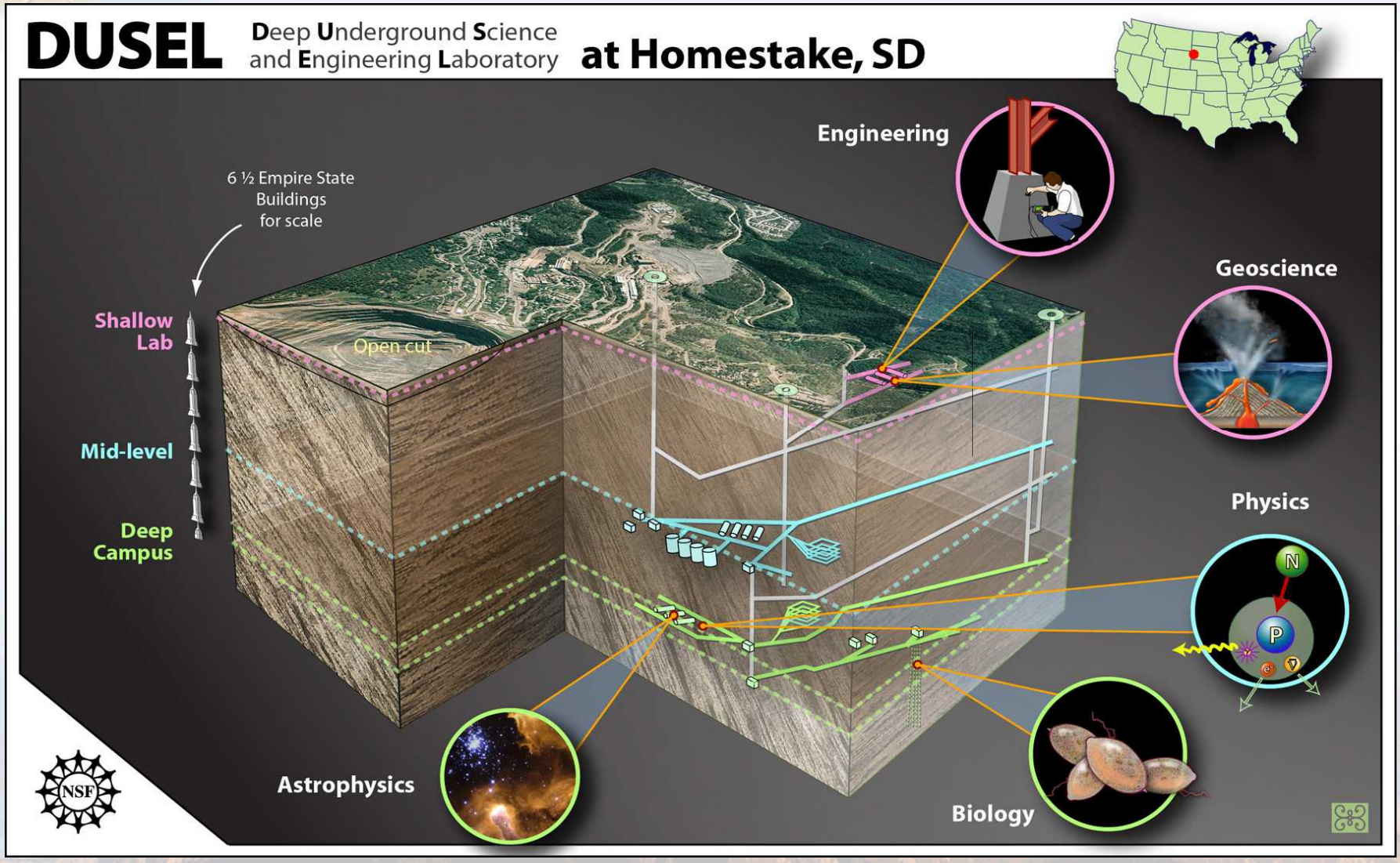


ONKALO URL - Finland

- ONKALO ramp, shaft and infrastructure construction cost (down to main level) ~$90M
- Posiva Oy annual budget approx. $50M to $100M
- Discussion?
  - Anticipated staffing?
  - Other costs?
  - Funding-imposed limits?



URLs for Physical/Chemical/Biological Sciences Research Example: DUSEL (formerly Homestake)



Exercise: URL Cost Analysis

- Infrastructure Improvements
- Underground Construction
- Shaft Construction
- Management/Operation/Maintenance
- R&D Testing (not incl. off-site science support; all particpants)
- Summary
  - Construction (total cost)
  - Operation (annual)

Example #1 URL Cost Analyses

Use existing tunnel, utilities & facilities
Limited infrastructure improvements
Adit access; no shaft or ramp
On-site management
International cooperative R&D projects

	Low $M	High $M
• Infrastructure Improvements		
	0	0
• Underground Construction		
	0	0
• Shaft Construction		
	0	0
• Management/Operation/Maintenance		
	0	0
• R&D Testing (not incl. off-site science support)	0	0
• **Summary**		
– **Construction**	**0**	**0**
– **Operation**	**0**	**0**

Example #2 URL Cost Analyses

Purpose-built surface & underground
Extensive infrastructure improvements
Shaft access
On-site management, visitor center
International cooperative R&D projects

	Low $M	High $M
• Infrastructure Improvements		
	0	1
• Underground Construction		
	0	2
• Shaft Construction		
	0	3
• Management/Operation/Maintenance		
	0	4
• R&D Testing (not incl. off-site science support)	0	5
• **Summary**		
– **Construction**	**0**	**6**
– **Operation**	**0**	**9**

URL Planning Considerations

- **Pre-Existing Surface and Underground Facilities**
  - Activities such as mining (seismic, ventilation, other interference)
  - Ownership and access; pre-existing contamination and other liabilities
  - Availability of electrical power, fresh water, etc.
  - Ground stability and maintenance
  - Mine water quality, discharge and pumping requirements
  - Test planning and test-test interference
  - Project management and scientific steering framework
  - Training/educational opportunities
- **Purpose-Built (in addition to most of the above)**
  - Funding, cost-sharing
  - Site characterization and site selection
  - Incorporation in final repository or other facilities
  - Legal/regulatory permitting and approvals
  - Engineering design, contractor procurement, and construction management

Summary – Major URL Cost Elements

- Infrastructure
  - Surface facilities and utilities (electrical power, fresh water, etc.)
  - Use existing→ Save full cost of $20M to $100M
- Underground Construction
  - Tunneling: up to ~$10k/meter including ground support
- Shaft/Ramp Construction
  - Shaft sinking/boring cost 2X to 5X horizontal tunneling; $10M to $50M each
  - Ramp cost similar to tunneling, but ramps are 10X longer than shafts
- Management/Operation/Maintenance
  - 10 to 50+ workers → $1M to $30M/year
- R&D Testing
  - Four European URLs spend $15M to $30M/year (equiv.; Andersson 1999)
  - Include peer review/steering panel
- Summary
  - URL development: $20M to $300M
  - Operation and testing : $15M to $60M/year