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# MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Laser Interferometer Gravitational Wave Observatory (LIGO) Project

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Refer to: LIGO-T960149-00-R
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Subject: **Concept and estimated cost for upgraded MIT R&D vacuum system**

I drew up a vacuum envelope schematic (Fig. 1) which I think reflects your vision for the proposed MIT vacuum system's capabilities. Since we haven't settled on definite make-or-break requirements it's hard to be concrete, but perhaps we can firm it up after digesting some rough numbers. In the meantime I took some semi-arbitrary boundary conditions:

- 4 chambers, HAM type (each standard HAM includes a stiff-ish 60" bellows at one end); intrinsically compatible with LIGO stacks/suspensions
- 30" beam tubes, total L ~ 25 m
- NO big gate valves (can buy extra pumps and blankoffs for price of a 30" gate, if isolation is needed later; annulus system reduces leakcheck application for valves)
- LIGO-standard annulus system (attached mini ion pumps, portable turbo stand for roughing)
- NO atmospheric compensators; facility floors resist vacuum loads and dead weight (~15k lbs pullout, ~35k lbs compression); actual existing floor strength unknown, could be a big cost driver if too weak
- ion pumped in normal operation (guessing 2000 l/s needed to maintain reasonable pump life)
- dry wide-range turbo w/dry roughpump (little membrane pump backs turbo at high vacuum); existing Balzers 520 may be marginal to start IP's, so I added a new 1000 l/s turbo pending a closer look
- all pumps valved (turbo valve interlocked pneumatic, others manual)
- softwall cleanrooms
- portable electric-hoist gantry for handling doors, tubes, pumps, etc. adapted from existing
- class 100 dry air backfill/purge system, 50 scfm
- bakeout capability (permanently installed)

I should also point out that I am only working up an EMPTY vacuum envelope. We obviously need an internal support structure for each chamber and some number of isolation stacks, depending on what we initially and later put inside. For ROM purposes, excluding in-house engineering (I assume Detector SEI will provide prints), I believe the cost book number for HAM guts is just over $105k/chamber installed.

I talked a little with John about fabrication of HAM chambers. Based on PSI's internal schedule (which has generally proven a tad optimistic) we guessed that from a signed contract, with a complete set of blueprints and specs in hand, to cutting metal would be a minimum of 4 months (mainly to specifiy and procure material). After that, probably 8 weeks of fabrication for the first chamber (there are many jigs and fixtures to make; we're assuming PSI isn't doing this for the moment, see below). The rest of the chambers would take ~4 weeks each, assuming low-tech steps like cutting, rolling and final assembly are done in parallel (fixturing, weld prep and welding steps are done sequentially, due to jigs and highly skilled labor involved). Leakchecking, repairs and cleaning would add about another 4 weeks; if a factory bakeout is called for, I'd guess another 2 weeks. So figure about 9 - 11 months from contract signing to delivery. Add a month (optimistically) at the beginning to write/review a spec and RFP, 30 days to respond, 30 days to select a bidder and obtain approval, and I think we're looking at 12 - 14 months from the day the funding is approved till we begin assembly.

To run the procurement and monitor the fabrication contract, I put in 1/2 man-year of experienced engineering. This may be light, and it depends on many unknowns. For the time being I'm also assuming the assembly is NOT made part of the subcontract, but that we try to do that ourselves. I think our existing crew supervising 2 hired hands could maybe do it in 3 months, so I put in 1/2 man-year[1]. This may also be light, and frankly I would prefer to sub the installation to the fabricator if feasible (even if it's going to nominally cost more, it will remove or reduce QA risks). Remember that we also have to consider integrating our own equipment after the vessels are commissioned.

John was concerned that even fabrication wouldn't be such a turnkey process. It isn't trivial to build to a third party's design, and the experience gained in making the first chamber is pretty important (PSI evidently weighed this heavily enough to build a prototype at their own risk). Commercial factors aside (and there are many), giving the job to PSI has its advantages. Assuming we could obtain a good price, the PSI fabrication for Louisiana should wind up toward the end of '97, so that's probably the earliest time they would be able to start.

Another option, which I assumed was off the table for now, is to go with a new custom design. Of course this has many of the same disadvantages and some new ones. One is nonrecurrent design engineering, which PSI put at about 1 man-year to go from the detailed specification drawings we supplied to final fab drawings. We also need to add the time on our end to make those new specs rather than rehash old ones. But if our requirements are significantly relaxed (especially interior volume and LIGO compatibility) it might be a good trade. Think of the NRE as about one more HAM chamber's worth. Finally, not that you need more options, the 40-meter Mk II chambers are a capable, conservative design, IMHO.

Anyway, with the above boundary conditions and the sketch (attached below) I come up with the rough costs in Table 1. Estimating basis is mostly the PSI proposal, but I put in notes where I did something else (e.g. bakeout, where I took a wild ROM guess).

To conclude, let me offer a personal judgement. I feel the procurement and assembly logistics for this full system, *in a time commensurate with our lab move* (i.e. well before January '98), are mar-

1. To be fair, one should compare our in-house labor investment with whatever we'd be doing "otherwise;" so I'm not being rigorous about including our own (my, Tom, or Ed's) time. But in raw form I'd say it's a 4-man job with a full-time supervisor for 3 months.

ginal at best. I also think the investment is very high in capacity we will only fully exploit 2 or 3 years down the line. Both points argue strongly for a phased approach.

I can think of several possibilities, but fabricating "new" chambers (even a reduced number) in a time commensurate with the lab move is a problem in most of them. Moving the existing PNI vacuum envelope is not very feasible because of the overhead crane hook height required to operate it (in addition to the further investment of time and money into crap with no future).

Since the first use will be to reassemble the PNI experiment to check out the high-power YAG, I think we could start operations with a minimum of two chambers. I'd suggest we consider if it's feasible to "borrow" the spare HAM chamber (we are making 1 extra) and perhaps one more (e.g. from the output optics chain at Louisiana) while getting replacements built. I can't say if this works schedule-wise, and it may have commercial impact (e.g. on the PSI installation) but it's the best option I've thought of within the stated boundary conditions. Finally, in virtually any scenario we need to get an engineer on board (contract, CSR or whatever) ASAP to manage it.

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**Table 1: vacuum system ROM cost estimate (PNI components recycled as noted)**

| Item | Description | Unit cost ($k) | No. Req. | Ext. ($k) | Sub-total ($k) | Comments |
|---|---|---|---|---|---|---|
| | **Vacuum envelope:** | | | | **861.0** | |
| 1 | HAM chamber, incl. side doors & 60" ID expansion joint | 150 | 4 | 600 | | escalated PSI figure |
| 2 | End cap, 60"ID, ported | 17 | 3 | 51 | | similar to PSI A-11 |
| 3 | Reducer A, 60" X 30" | 20 | 5 | 100 | | similar to PSI A-5 |
| 4 | Reducer B, 84" X 30" | 15 | 1 | 15 | | modify 1 std. HAM side door (wag) |
| 5 | Tube support/thrust anchor | 2 | 5 | 10 | | MEZ wag (welded carbon steel) |
| 6 | gimbaled bellows, 30", flanged | 15 | 2 | 30 | | scaled down PSI BE-4 |
| 7 | tube section, 3 m, flanged & ported | 15 | 2 | 30 | | like PSI B-2 but shorter |
| 8 | tube section, 12 m, flanged & ported | 25 | 1 | 25 | | like PSI B-2 |
| | **Pumping & instrumentation:** | | | | **129.5** | |
| 9 | Ion pump, 500 l/s noble diode, w/supply | 12 | 2 | 24 | | Mk II PO, use 2 PNI IP's (total 4 req'd) |
| 10 | IP 8" isolation gate valve (man.) | 2.5 | 3 | 7.5 | | reuse one existing on PNI (total 4 req'd) |
| 11 | Dry roughing pump, 110 m^3/hr | 25 | 1 | 25 | | Edwards QDP80? |
| 12 | Membrane backing pump | 3 | 0 | 0 | | MD4; use existing |
| 13 | 1000 l/s turbopump & controller | 35 | 1 | 35 | | PNI 520 pump marginal to start IP's (?) |
| 14 | TP 10" isolation gate valve (pneumatic) | 3.5 | 1 | 3.5 | | VAT or equiv. |
| 15 | misc. pump station h/w & cabling | 5 | lot | 5 | | flex hoses, etc. |
| 16 | annulus ion pump w/controller | 2.5 | 4 | 10 | | 25 l/s |
| 17 | annulus ion pump plumbing/valve set | 2 | 4 | 8 | | viton-sealed |
| 18 | annulus roughing station | 8 | 0 | 0 | | reuse Balzers TSU065 from PNI ? |
| 19 | annulus roughing hardware | 2 | lot | 2 | | flex hoses etc. |
| 20 | residual gas analyzer | 10 | 0 | 0 | | reuse PNI RGA head (bake temp.??) |
| 21 | vacuum gauge setup w/controller | 3.5 | 1 | 3.5 | | PNI gauges obsolete & unreliable |
| 22 | all-metal valves for RGA and gauges | 1.5 | 4 | 6 | | 1.5" VAT |
| | **Infrastructure & support:** | | | | **56.5** | |
| 23 | refurbish/upgrade gantry crane | 4.5 | 1 | 4.5 | | modify gantry, add VFD hoist |
| 24 | softwall clean room | 10 | 1 | 10 | | modify PNI unit (~30 k for new) |
| 25 | 50 cfm backfill/purge system | 35 | 1 | 35 | | scaled PSI end/mid station unit (?) |
| 26 | backfill/purge controller & valves | 5 | 1 | 5 | | guess |
| 27 | backfill/purge plumbing | 2 | 1 | 2 | | guess |
| | **Bakeout system:** | | | | **120.0** | |
| 28 | HAM heater blanket sets | 10 | 4 | 40 | | guess (PSI no's hard to scale) |
| 29 | tube heater blanket sets | 5 | 4 | 20 | | guess |
| 30 | misc. bakeout blankets | 1 | 10 | 10 | | guess |
| 31 | bakeout controllers (50 kW) | 25 | 2 | 50 | | guess |
| | **In-house manpower:** | | | | **130.0** | |
| 32 | spec. & procurement, contract mgmt. | 140 | .5MY | 70 | | loaded; senior contract engineer |
| 33 | installation | 120 | .5MY | 60 | | loaded; jr. eng/technician (avg.) |
| | | | | | | |
| | **TOTAL EST.** | | | | **1,297.0** | |

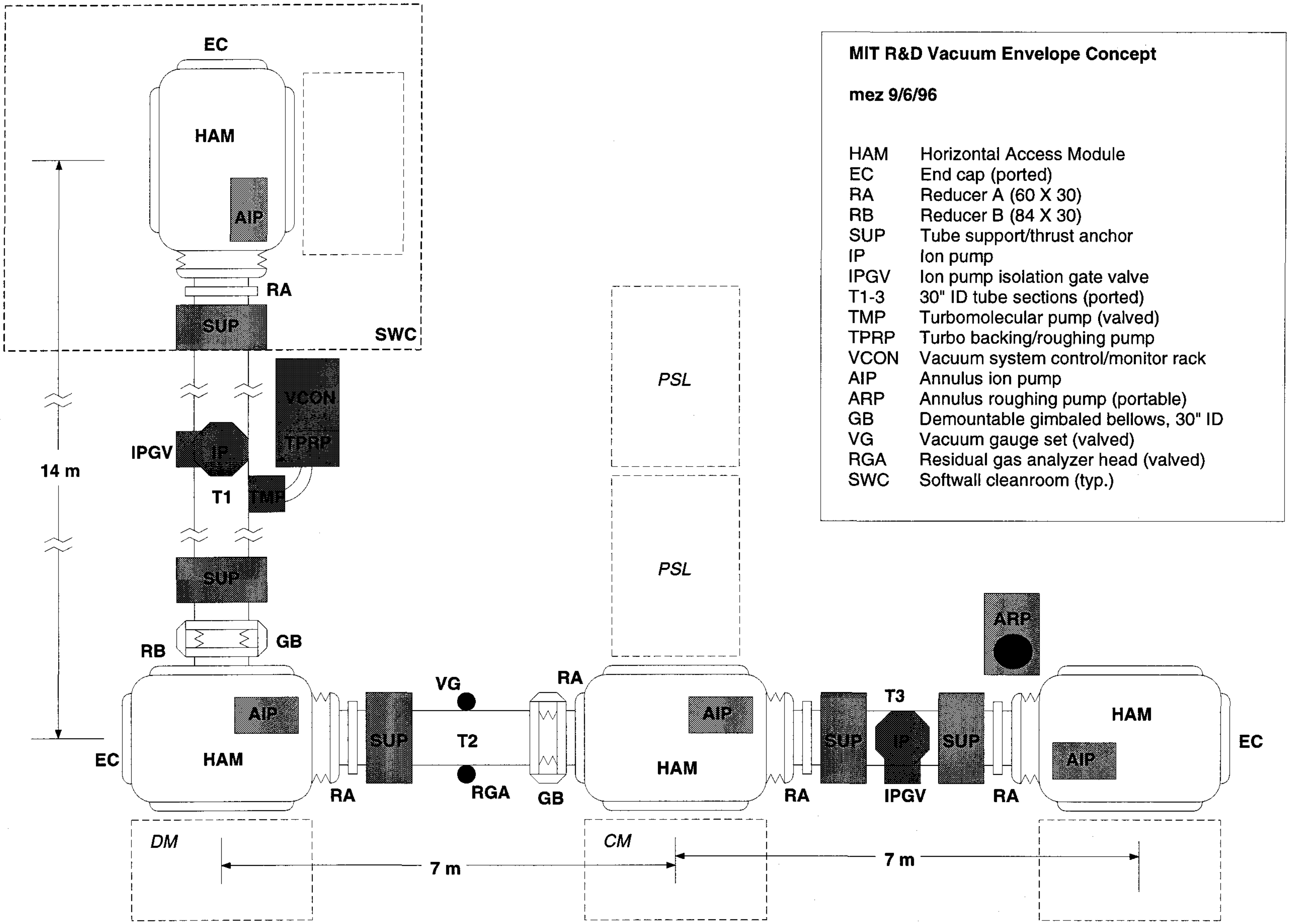


**Figure 1: MIT R&D vacuum envelope concept. 2 more IP's are under the tubes.**