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ILC Dump Issues That May Need Further Work or Study

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This is a second pass at a list of some issues in the design and performance of the ILC dumps as presented in the RDR and supporting documents that may need further work in analysis, experimental tests, engineering or prototyping in the EDR phase of the project. This is the starting point for discussion for a tally of work-to-be-done, with the help of all in the ILC Dump team, by work packages in the EDR phase aimed at reducing cost or technical risk. We have clear instructions from the Project Managers at the BDS KOM to take a sharp look at all aspects of the systems to find ways to make them cheaper and/or more robust. Some of the questions here may reflect my poor understanding of the issues, and the answers to some concerns outlined here may be obvious or already answered somewhere previously that I am not aware of. Some of the issues noted here are in the line of straight-forward design problems that require work by engineers and designers and do not require high priority R&D in the EDR phase to eliminate risks, but are listed here for the complete picture. Also some of the issues will be covered by work in other groups (MPS and BCS systems, CFS, Radiation Safety, detector backgrounds, etc) and we need to coordinate with them to asses the risks and cost tradeoffs for the dump systems. More discussions with Andrei, Lew, Yury, Takashi, Dieter, Tom, Eric and Chris Densham and his UK colleagues are needed to pool our thoughts so we can construct a sensible set of EDR work packages for the dump systems.

The main sources of information were:
RDR Chapter 3
S4 presentation by Tom 12 March 2007.
Presentation by Yury at LCWS07
Presentation by Takashi at IRENG07
annotated_ILC2006e_BDS_layout.pdf
Numerous good works by Lew, Yury, and Takashi at the BDS meetings, and Chris Densham and colleagues.

The ILC dumps, especially the Main Dumps and Tune-up Dumps, are affected by parameters and design choices in many areas where tradeoffs will be made that affect physics performance of the ILC, the cost, and technical risk. These include:

- mechanical design of the dump vessels and ancillary facilities (high pressure cooling loops, water jets, pumps, filters, …) including capacities, locations, backups, expected lifetime and reliability, installation and maintenance, …
- mechanical design of the dump windows and possible remote controlled changers, acceptable risk of failure, consequences when they fail, procedures for recovery, …
- engineering details of materials for use in high temperature and radiation for windows, flanges, pressure vessels, tail catcher absorber, pipes, connections, ,
- size and strength of the structures for vibrations, beam induced pressure waves, expected life time, maintenance requirements, …,

- cavern size and location affects cost, access for installation and maintenance, crane coverage, proximity to adjacent incoming beam line for radiation and vibrations, …,
- shielding size required for protection of adjacent equipment, personnel and environment; access for dump inspection and repair work, …,
- expected and permissible irradiation and activation of nearby equipment in dump system and on adjacent beam line, time for cool down for inspection and maintenance, damage to magnets, movers, sensors, cables, electronics…
- beam operating procedures and allowed beam parameter phase space from excursions during beam tuning, settings of extraction line quads and bends that could produce large deflections and focusing errors that could make spot size too small and damage windows.
- MPS and BCS systems -- devices, electronics and software for detecting and taking action for miss steering and accident conditions and to prevent beam on when proper operating conditions and state of equipment are not met.
- instrumentation required to assure proper and safe operation of the dump (pressure and temperature sensors, water and gas flow meters, vacuum sensors, fast valves, sweeping magnets, possible passive beam expander/spoiler, radiation detectors, air monitors, …) what, where, how do they work, what are the potential failure modes and probability, what redundancy is required?
- maintenance requirements and procedures for safety and performance inspections, looking for leaks, etc, frequency and cost for window changes, filter changes, required access space for inspections and repairs on pumps and water systems in radioactive area.
- radiation safety standards that set allowable dose to maintenance and repair workers helps determine size and locations of shielding and cool down times before access; permissible dose into the environment air and water determines required level of protection to prevent exposure and mitigate failures with sumps, air dryers, backup systems.
- policies and procedures specifying acceptable level of risk to equipment, personnel, environment. How safe is safe enough?
- acceptable level of damage to experimental equipment in event of major failures or damage to pressure vessel, windows, or water systems that could release radioactive water. Water in the beam pipe and in the dump enclosure and sumps may be accepted, but otherwise must be contained ??
- dump physics of pressure wave generation and propagation in the water that could effect the mechanical integrity of the dump vessel and windows.

Some issues and questions in no particular order and not prioritized, for which the answers from study, modeling, prototyping, or hardware tests could affect the technical risks and the cost of the ILC dump systems:

1. Regulatory Environment: What is the (site dependent) regulatory environment for:
    - High-pressure vessels with radioactive liquids: What design codes apply: those for boilers, reactor vessels etc?
    - Seismic design: equipment to be braced to withstand what acceleration, and after the design earthquake to have damage limited to what level.
    - Radiation safety rules: for people, air, water, the ground.
    - OSHA rules for access, egress, safety lighting, stairs, noise, confined spaces,…

2. Required Level of Safety: What are the Laboratory Policies and Practices for the required level of protection for personnel safety and to prevent damage to equipment? How safe is safe enough? How many independent devices or features of the design are required to ensure that the systems will perform without failure up to some level of probability. At SLAC it is required to have three independent methods (stoppers, magnet interlocks etc) to ensure that the beam cannot come on when people enter the beam housing. What frequency of failure of the dump systems (most likely the rupture of the window) will be permitted with some probability (once per year, once per 10 years, never) and how many independent instruments or design features at what cost will be required (with their accompanying failure modes) to achieve that level of risk. I imagine that, if a dump window were to fail and deliver thousands of gallons of radioactive water into the vacuum system or onto the floor, the laboratory would be shut down for quite some time. This is a classic risk/benefit problem where the more levels of safety built in the more reliable and costly the dumps will be.
3. Allowable Dump Failure Modes and Damage: If there is a failure of the dump containment system what level of damage is allowed by the Laboratory Policies and Practices? Is the design to expect that for a window failure radioactive water gets into the beam vacuum pipe, but not out of the pipe onto the floor? In which case it is expected that the vacuum pipes, pumps, etc will be designed and instrumented to permit recovery at reasonable cost from this damage. If it can be shown that the parameters (pressure, rupture forces, water volume etc) could be contained in the vacuum pipe, then secondary containment (sumps, pumps, water drying equipment, enclosed air spaces all mentioned in the RDR) could be limited to smaller area and cost less. Analysis needs to be done on possible containment failures (leaks, pipe problems, pump problems, etc) to identify the extent of damage that would need to be mitigated by the design (sumps, dryers, etc) and for which recovery at modest cost should be planned.
4. Components and Design Features Other Than Dumps To Be Considered: What components of the BDS do we need to include when analyzing the risk/benefit tradeoffs to determine the cost and risk performance of the dumps? Clearly it is not just the dump vessels, windows, and pipes, but also extends to such things as the MPS (Machine Protection System) and the BCS (Beam Containment System), the location and size of the cavern, the beam line optics, beam operations and much more. It may be that if the windows cannot be adequately protected in time (how many bunches?) from errors in beam conditions by the BCS devices to prevent damage to the windows, then other methods (e.g. passive beam expanders, longer drift distance to the dump) may need to be included in the design. The whole system needs to be included in the analysis to minimize cost and technical risk.
5. Dump Windows are a Major Problem: The dump windows are clearly the most vulnerable components. Some questions that need answers:
    - Window design and materials: What material should be used (Ti alloys?), and what design (shape, thickness, flanges…?) construction style (welding, flange types, bolts, …)
    - Window material performance in high intensity electron beam: How do the window materials behave in strength after extended exposure to radiation and shock from the beam, including static and cyclic shock from thermal stress and pressure stress from shock waves in the water? Is the strength of the material

decreased by modification of the metal structure from high intensity electron bombardment (from displaced atoms, spallation reaction components, migration of alloy elements to grain boundaries, changes in crystal structure, etc)?

- Window lifetime: How long can a window be expected to last, and with what probability of failure? Do we need to build prototypes and do damage tests?
- Failure modes: What are the failure modes of windows? Do they get pin holes and weep, or do they crack, erode, rupture, etc.
- Window changer: Do we need remotely controlled window changers? If so what are the features and functions required in the design to facilitate remote handling, mechanical reliability, adequate cooling by the water jets, shielding to permit moving parts, etc..
- Maintenance Inspections: Should the design permit window inspections by partial disassembly of the beam line?
- Beam Parameters at the Dumps: What range of beam parameters are possible and/or permitted on the dumps? Evaluate the phase space of spot size, beam position, bunch charge, number of bunches, with and without sweeping that is possible on the dump windows and determine the values that are allowed on the window (and dump water) that would keep temperature and pressure excursions within permissible range. Some work has already been done on this for the Main Dumps, but it needs to be carefully checked, and also extended to include the Tune-up Dumps and other dumps in the Linac and DR complex. Performance of other parts of the Beam Delivery System will need to be analyzed and designed so that the allowed phase space is not violated, such as control of magnet settings, BCS and MPS equipment, magnet interlocks, water system interlocks, sweep system, kicker magnets into the Tune-up Dump, latency of error detection systems from signal propagation time and electronics, operations and tuning procedures, etc.
- Auxiliary Equipment for Dump Operation and Protection: What auxiliary equipment must be included in the dump systems to assist in the operation and survivability of the dumps? Some items are mentioned in the RDR: doughnut collimators to mask the window flanges; a secondary window up-beam of the main window with gas between for cooling. (Can this work? Does it help? The gas could be inspected by sensors to look for water weeping through grain boundary fractures in the main window, etc); passive beam expander (could be a water cooled rotating wheel after the sweep magnets to blow up beam size by multiple scattering. Would this help? How would it work? Is it needed?)
- Is the RDR Preliminary Design Adequate? Does a risk/failure analysis of the system suggest that failure probabilities are too high and that design changes may be needed. Lengthening the distance to the IP would increase the beam spot size; adding magnets (quads) to the extraction line could be used to expand the spot size width (but shrink the height) to spread the energy deposition over more widely separated portions of the window material.
- Equipment to Monitor Windows and Mitigate Window Failures: What equipment is needed to deal with the possible weeping or rupture of the windows? This might be vacuum sensors and fast valves in the extraction line for fast isolation of vacuum pumps; temperatures sensors on or near the windows; design the vacuum

pipe up-beam of the dump specifically as a water trap that can be isolated by fast valves, and evacuated and recovered after window failure.

- Equipment to Monitor Dump Performance and Prevent Failures: There will need to be sensors for water pressure, flow, temperature; radiation detectors to detect errant beam; interlocks to prevent beam on or shut beam off when dump conditions or equipment state is not allowed.
- Beam Containment and Accident Prevention Design Philosophy: In the Laboratory Policies and Practices will it be required that all I&C systems that help prevent dangerous accidents (e.g dump window failure) be hard wired and based on physical states of devices, or will it be permissible to have software in the protection system that could be vulnerable to poor design, improper modifications, or computer failures? The software in the system for beam tuning and feedback might know that the beam is not proper at the Main Dump, and could in principle be used to turn off the beam, or deflect it to the Tune-up Dump. Modern PPS systems use programmable logic for the states of doors and stoppers to prevent radiation exposure to people, but is that permitted in the Dump system? Or must the error detection and accident prevention be built with redundant devices in copper and steel?

6. Prompt and Residual Radiation from Dumps: Another major area for analysis and design work to is to minimize cost and risk from radiation in the dumps and adjoining areas. For this discussion assume that the dump vessel, windows and cooling system is adequately designed to handle the heat, remove the evolved hydrogen and oxygen, filter out the ^{7}Be and contain the tritium in the water as long as it remains intact, and that the radiation in the water is all handled properly. In addition to the activated water there is prompt and residual (activation) radiation in the Dump House, as well as in the Service Hall and nearby beam line that needs to be considered. A few questions that come to mind (some with preliminary answers in the RDR that should be confirmed) are:
    - Shielding Material and Thickness for Prompt Radiation: What shielding material and how thick is needed to protect the nearby equipment in the Dump House and adjoining beam line from prompt radiation damage? The RDR says 50 cm Fe, 150 cm concrete. Is this a solid number or does it need further study?
    - Evaluate the Prompt Radiation for Various Scenarios: What is the prompt radiation level for various beam conditions in the Dump House, in the Service Hall, in the adjacent incoming beam line, and up-beam in the extraction line from doughnut collimators that will affect performance and possibly cause damage to stuff like cables, sensors, gaskets, filters, electronics, safety lighting, etc. Prompt neutron and gamma radiation spewing out like a gas from the dumps and collimators can cause background in signals in devices used for physics data, for beam line instrumentation and local monitoring, such as TV cameras, phototubes, diodes, and ion chambers etc, that would interfere with their function. Up-beam 100 m to 150 m from the Main Dump there will be lots of detector elements for GAMCAL, the Compton polarimeter and the synchrotron stripe energy spectrometer that will need to be adequately shielded from the Main Dump. A few meters away from the Main Dump and Tune-up Dump are magnets and collimators with their associated movers and electronics. Levels of prompt radiation and integrated dose need to be evaluated with the relevant programs

(FLUKA, MARS, etc) to look for hot spots, weaknesses in shielding thickness, choice of materials, optimizing strategies for deploying shielding, etc. Experience at SLAC Beam Dump East shows that some equipment that may be desired, or even required, for proper operation survives poorly in the ambient radiation. Amplifiers and other electronics die, light bulbs quit working, cables rot, labels fall off, phones quit, wood and some plastics cannot be used, and so forth. The overall performance can be improved if these problems are anticipated and accounted for at the beginning.

- Shielding of Residual Radiation in ILC Equipment: What is the expected level of activation of the dump vessel, windows and flanges, water pipes, shielding walls, up-beam vacuum pipe, doughnut collimators, pump equipment, filters, the adjacent Beam Delivery System, and the beam pipe up-beam of the dump? This information would be useful for optimizing the choices of materials, understanding the risks from radiation exposure during access for inspections and maintenance, determining cool down times for access, and generally understanding that the design is adequate to meet the regulatory rules for residual radiation protection. For example at SLAC Beam Dump East the filter that removes ^{7}Be used to be located in a canister that sat right next to the walkway required for entrance to the dump pump area. It was unshielded, so when people entered the area, especially after short cool down time, they were exposed to radiation from the filtered isotopes. This design flaw was be easily fixed by putting the filter in an area away from the walkway, and by shielding it. There may be other similar such features of the dump system that might be discovered by analysis and prevented in the design.
- Minimizing Activation and Residual Radiation by Design: It is possible to partially minimize the activation by careful and clever design. Location and choices of materials for the shielding are important. At SLAC the concrete near the beam dumps and collimators was loaded with boron to help reduce the neutron flux. It may be beneficial to investigate other similar strategies, such as surrounding the dump vessel with boron-loaded and hydrogen-rich compounds, making the shielding walls thicker in some directions, shielding the beam pipe between the sweep magnets and the dump, etc. Choices of materials for the equipment can also reduce activation and mitigate residual radiation. Using lower Z materials, where appropriate, can prevent build up of longer-lived activation products. Al cools down faster than steel or copper, so it might be advantageous to make some components (dump vessel and nearby vacuum and water pipes) of Al so they could be accessed for work more readily after beam off. Nikolai Mokhov and colleagues at Fermi lab have shown that putting a few inches (5 inches) of marble outside of the iron shielding of high power collimators and dumps can significantly reduce the radiation from lower energy gammas (few MeV) from activation of the iron, making access easier and cool down times shorter. The marble does not become activated (if it is mostly pure $CaCO_3$), and it is high enough Z to be an effective shield. Such ideas need to be incorporated into the ILC Dump design.
- Shielding Required to Prevent Environmental Activation: What shielding material and thickness is needed to prevent activation of ground water consistent

with the prevailing (site dependent) environmental regulations? Estimates in the RDR should be confirmed. This could be a large cost for wet sites

7. Location and Size of the Dump House and Dump Service Hall: Here are a few comments on the preliminary layout of the dump caverns. The locations and sizes of the caverns for the RDR are shown in the figure: annotated_ILC2006e_BDS_layout.pdf.
   - Proximity of Dumps to Adjacent Beam Lines: The position of the dumps with respect to the components of the adjacent beam line should be considered. In the RDR plan (IP-to-Main Dump = 300 m) the Main Dumps and Tune-up Dumps are a few meters from magnets and collimators (with movers, BPM's etc) in the beam delivery system. The space required for the Beam Delivery System limits the shielding wall thickness and it may be too thin to be adequate. If the Main Dump were shifted about 40 or 50 meters farther down-beam, then the dump could sit adjacent to a section of beam delivery line without magnets. In that case one could consider expanding the dump shield across the adjacent beam line, with a hole for the beam pipe, to increase the effectiveness of the shielding. In addition if the Main Dump were shifted about 50 m down beam, then there may be some advantages to connecting the caverns and related equipment (cranes, walkways, etc) provided for the muon wall to that provided for the Main Dump, with synergies, savings and better performance. The iron wall could be partial shielding for the dump. The RDR layout shows the clearance between the Tune-Up Dump vessel and the neighboring beam line elements to be less than one meter, which is clearly not enough space. The distance or the bend angle to the Tune-up Dumps probably needs to be increased.
   - Residual Radiation. Is the RDR design optimized when considering residual radiation? Consider access to the dump equipment and to the adjacent beam line for maintenance and inspections. Will the level of radiation after some reasonable cool down time (a few hours)? interfere with routine access? Will the Dump House and the adjacent beam line become Radioactive Contamination Areas (dust on floors and walls gets radioactive) so higher levels of PPE (personnel protective equipment, e.g bunny suits, gloves etc) are required for entry, at cost in effort and schedules? [During E158 at SLAC when about 10 kW (not 18 MW) of radiation was deposited in collimators inside large magnets that were in turn covered by thick walls of lead and concrete, after a few weeks of running the walls and floors were activated and the whole area was a Radioactive Contamination Area that limited entry to short periods and under strict supervision. The area was roped off to access for months after the experiment.] If studies show that activation will create Radioactive Contamination Areas, it might be preferable to make the caverns a little bigger so more local shielding around the dump vessel can be employed, and so more space can be available for positioning the service equipment, providing walkways behind shielding, etc. This initial investment in infrastructure might pay off in more physics productivity in the long run.
   - Vibrations: Another serious issue that needs to be considered when evaluating the performance of the large dumps in close proximity to the Beam Delivery System is the potential for large vibrations produced by the fast moving water in the pipes and the dump vessel, and from the nearby pump and heat exchanger equipment. SLAC Beam Dump East provides a glimpse of what the scale of the problem

could be. Attached below are few pictures of the dump vessel, the water pipes, and the pump and heat exchanger area a few meters up beam adjacent to the beam line. Beam Dump East has a power capacity of 2 MW (not 18 MW). It was not built with vibration suppression in mind, but other wise it looks much like the concepts imagined for the ILC Main and Tune-up Dumps, with ~1.5 m diameter dump vessel fed by water into a vortex-like flow at velocities ~ 1m/s, with the pumps and heat exchangers located in a separate house some meters up beam off to the side of the beam line. Inspection of this area when the pumps are on finds lots of noise in the service room from pump equipment and water circulation. The water pipes feeding the dump, the dump vessel, all the nearby stands, rails for the support system, the supports, and even the cable trays are vibrating like crazy. Vibrations are large and annoying to the touch. Vibrations of ~100 microns can be felt by hand, so these are much larger. This would be a bad thing to have running right next to a Beam Delivery System where components need to be stable to tens of nm. A feature of the Beam Dump East arrangement is that high velocity water must be routed around corners to get from the pump room down the beam line and into the dump. Turning corners with high velocity water flow generates turbulence and vibrations. The RDR dump arrangement has the same geometry with pump room up-beam and water pipes running tens of meters parallel to the Beam Delivery System and making a hard turn into the dump. To be fair, SLAC Beam Dump East does not have any vibration suppression features. Also the plumbing has numerous unnecessary transitions and irregularities in the pipe profile that generate turbulence, so the situation could be made better by careful design. The message is that for the ILC systems in close proximity to the Beam Delivery System, vibration analysis and suppression techniques must be employed when working with large volumes of high velocity water.

8. Equipment Layout: A preliminary dump equipment layout is shown in the drawing from RAL, slide 6 of Tom's S4 presentation. This drawing prompts some observations on design issues that might be considered. (This layout is not the same as the RDR which has the dump and service equipment in separate caverns. Apologies if these comments are off base because the designs are understood to be preliminary):
    - Dump Vessel Shielding: The design of the dump vessel shielding needs more study to make it efficient, compact, and adequate for both prompt and residual radiation. This will certainly involve various layers of materials (iron, perhaps marble, or other hydrogenous neutron suppressing materials) that must be arranged to fit in the tight space and also allow access to the dump vessel, the windows and the window changer (if needed). The local shielding around the dump vessel is sketched as a solid enclosure with no access unless roof and walls are removed. There needs to be access for periodic inspection and maintenance of the dump vessel (looking for leaks, fixing the changer mechanism, etc) after suitably long cool down times (months). In the RAL sketch the roof and one wall would need to be removed by the crane. If not then the dump and changer machine are locked into a tomb. It may be better to provide a movable door, perhaps with a chicane, to allow access. Such doors that do not take much space can be made with large masses on rollers with hydraulic or mechanical movers.

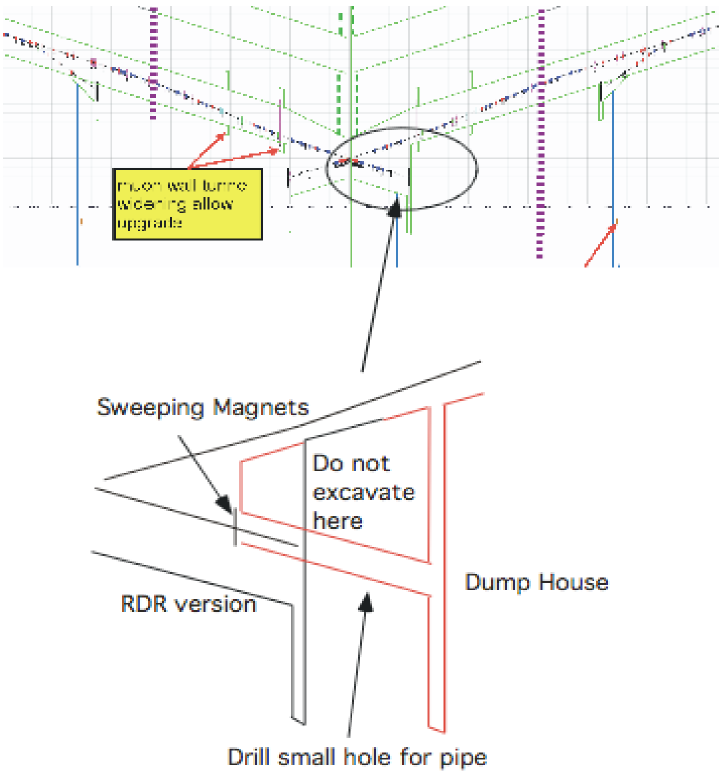
- <u>Crane Coverage and Capacity:</u> It seems necessary to provide crane coverage in the dump area for installation, maintenance and repairs of the heavy equipment. Cranes will be expensive and need to be designed to meet the requirements for weight, floor scope and hook height. The RDR plan with separate caverns for Dump Hall and Service Hall may require a separate crane in each hall, at more expense. The crane in the Dump Hall needs to be robust against radiation damage.
- <u>Installation Plan:</u> How is the steel and concrete and the large tanks and equipment to be brought to the dump location and installed? What are the construction scheduling implications for the dead-end arrangement of the Dump House and Service Hall? Is there sufficient space to permit significant equipment (portable lifts, jacks, replacement parts, leak checkers, emergency pumps, etc) to access the area after installation?
- <u>Access:</u> What will be the expected requirements for personnel and equipment access to the various areas (Service Hall, Dump Room, adjacent beam line, at the target window mechanism…) and is the access space and shielding adequate to the task. For example, in the RDR layout the Service Hall, with major industrial equipment needing periodic inspection and maintenance, is only accessible from the IR hall by going down the main tunnel on one side of the beam line squeezing past the entire extraction line system.
- <u>Air Control:</u> The RDR mentions enclosures to isolate the air in the dump system from the outside world to prevent radioactive products from leaking out in event of a failure of the cooling water containment. How is that to be done? How are the enclosures, the doors, filters, air driers, to be incorporated into the design?
- <u>Water Control:</u> The RDR mentions (and SLAC Beam Dump Ease has installed) sump basins under the dump vessel, and perhaps under critical components of the plumbing system to catch drips and big leaks if the containment fails? Are they needed, and if so how are they to be incorporated into the tight space requirements for the dumps and local shielding?
- <u>Window Changer:</u> Is a remote changer mechanism needed, and if so how is it to be designed to accommodate the requirements for window cooling jets, motion of the devices, inspections and verifications, etc…? Holes in the shielding for window changer mechanisms will provide a port for neutrons and gammas to leak out and activate the exposed area and would likely make the area around the outside end of the changer mechanism a hot spot. Perhaps it's a better strategy to design a changer mechanism that is entirely contained inside the dump shielding, that would could remove a window and store it locally, say down on the floor, while another portion of the mechanism can bring in a new window from the side. This could eliminate the need for holes in the shield wall, but would necessitate another access (sliding door) to permit periodic (after months long cool down) removal of old windows, bringing in new versions, and maintenance and repair of the changer mechanism.
- <u>Doughnut Collimator and Neutron Collimator:</u> (See more discussion below.) The RDR extraction line layout described by Yury shows one of the doughnut collimators COLW3 located just up beam of the dump vessel to protect the dump vessel and window flanges from the spray flux of beamsstrahlung. In another

context Takashi and co workers show a concrete collimator with 20 cm radius, and a tungsten collimator with 14.5cm radius just up beam of the dump vessel to stop the direct flux of neutrons from gong back into the silicon vertex detector at the IP. The design for these devices, and for integrating them into the vacuum system, providing alignment, cooling, and shielding has not been done. If they are required to be in the Main Dump package, they will introduce lots of new design and performance issues that need to be understood.

- Dump Storage: Does the design need to provide space for storage for a spare or decomissioned activated dump?

9. Differences Between the Main Dump and Tune-up Dump: The Tune-up Dumps are envisioned to be used both as a safe place to divert the beam when there is trouble down beam line, and a place to park the beam for extended time to tune at maximum power. They are both to be designed for the same maximum power and undisrupted beam. However there are other features that are different and may impact the design (and the cost).
    - Tune-up Dumps do not look back to the IR so they do not see beamsstraulung and do not need doughnut collimators or neutron collimators. This could impact the window design.
    - Both dumps need fast sweeping systems, and significant distance to the dump to allow for beam spot size growth. The optics are different and the spot sizes are not the same, which may impact the desired length of the tunnel.
    - The optics, beam line components and parameter spaces are different, which could lead to different levels of risk from errors or equipment failures.
    - They each sit adjacent to elements of the Beam Delivery System, but with different geometries and space for shielding, access, and concern for radiation and vibrations. Each needs to be analyzed.
    - The nearest path to the Tune-up Dumps is from the Shaft Service Cavern almost a kilometer away, which will affect access.
10. Some Possible Changes to the RDR Design to Reduce Risk/Improve Performance: Given the high cost for conventional facilities and for deep tunnel excavations it may be worthwhile to consider some variations on the RDR design that minimize the size of the dump tunnels and caverns.
    - Possible Improvements from Changes to Dump Tunnels: It might be possible to mitigate some of the issues discussed above by a simple change to the RDR tunnel design, as follows: If we decide that the tunnel length between the sweeping magnets and the beam dumps is not useful for any instrumentation and does not need access, as long as it keeps working as a vacuum pipe, then we could consider making that portion of the tunnel smaller, and longer, by using a tunnel drilling technique, instead of a digging technique. The idea for a Main Dump is sketched in the figure below, and Tune-up Dumps would be similar. Instead of making a wide tunnel between the sweeping magnets and the beam dump, it would be possible to drill a smaller hole to the Dump House using a drilling machine. Such hole drilling and lining are common in civil construction and special machines are available that can do this efficiently. The hole would be large enough (probably ~ 0.5 m diameter) to put in a liner pipe in sections, and then install the vacuum pipe in sections (perhaps with supporting railings etc).

This system would be made robust with a design to last decades. Drilled holes of similar size are planned at the ILC to connect the Service Tunnel to the Linac Tunnel. The vacuum pipe could be disassembled in sections and pulled out if there is trouble. Using a small pipe tunnel could have several advantages: the main tunnel would be smaller (cheaper) and would not require as much drill and blast excavation and wider roof support; the smaller tunnel could be cheaper (needs verification from CFS) and therefore might be made longer without increasing costs too much; the Beam Delivery System adjacent to the drilled area would not be as exposed to the dump line radiation; with the possibility of making the dump line longer we could move the dump farther from the nearby beam line and reduce risks from radiation and vibrations, and increase the spot size to reduce risk to the windows.



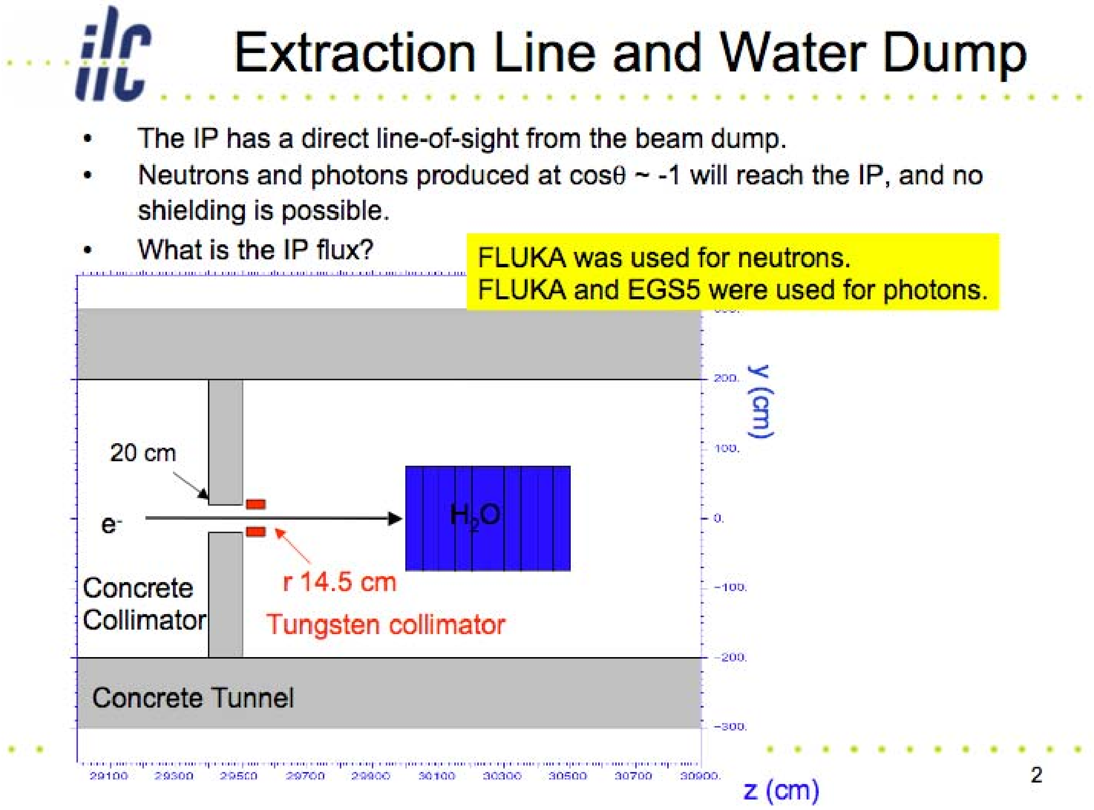
- <u>Possible Improvement from Changes to Dump Caverns</u> Another change that might be considered is to move the Dump Service Hall to the (near) surface and not have all the dump equipment in a deep cavern. The dump primary water loop could connect the dump vessel to the primary heat exchanger on the surface, and all the secondary heat exchangers and related equipment could be placed in a shielded hall, perhaps excavated just below the ground surface (typical site cavern depth is 100 m). There would be several consequences of such change: <u>Water pressure:</u> at 100 m depth, the water head in the primary loop would be about 15 bar, which is a bit larger than the 10 bar pressure currently considered for the target vessel, but probably can be handled; The circulating pump in the primary loop probably needs to be a “pusher” type located at the bottom of the loop near the dump vessel; Costs: (significant) costs would be eliminated for excavation and outfitting of the deep Dump Service Halls for very high reliability operation with limited access, as would all costs for deep access installation, maintenance, inspections, etc for the life of the project; Access: Equipment in the surface hall could be easily accessed for maintenance and repair without costly and time consuming approaches through the IR Hall and along the beam delivery line; Radiation safety: with longer primary water loops there would be larger volume of radioactive water to contend with in event of leaks; the radioactive water systems location near the surface and have to be considered in the environmental safety assessment. Vibrations: The dump water lines could be routed far from the beam delivery system, reducing risks from vibrations.

11. Doughnut Collimators: Some observations and questions about the proposed doughnut collimators that are auxiliary parts of the dump system designed to catch the wide angle spray of electrons, positrons and gammas mainly produced by beam collisions:
    - Locations: Are these collimators at the optimum locations with respect to background production and radiation hazards, based on expected spray power levels, efficiency for protecting down-beam components (apertures and lengths), and relationship to nearby components?
    - Power level required: What power level (instantaneous and average) are these collimators required to handle? Simulations show wide range in average power lost on the collimators depending on beam power, beam offsets, and alignment at the IP (see Yury's talk at LCWS07). Beam disruption will be modulated by the tuning with the feed back system for the first few hundred bunches as the beams are brought into collision. During that period there will be wild variations in instantaneous power on the collimators due to disruption and spray generated by beam offsets. The collimators need to be able to handle the expected levels of instantaneous power for short time periods. Yury and Lew both mentioned in various presentations that the Beam Delivery System needs to detect and efficiently prevent sustained operation (more than a few seconds?) with large beam offsets to prevent excessive power loss on the collimators. If the average power is never more than 40 kW then peripherally cooled metal will do, assuming they can handle the possibly larger instantaneous power for short bursts. If the average power is ever expected to be larger than 40 kW (after the upgrade to 1 TV cm energy), then the dump design may need to be water based (water cooled metal balls). [Note: Dieter designed and built 100 kW capacity edge cooled dumps of 1.45 m Al followed by 10 X_0 steel absorbers for the main dumps in the SLC extraction lines that could be a model for the doughnut collimators.] A peripherally cooled dump can be designed so that very little hydrogen and oxygen is evolved in the water so recombiners are not required, and tritium production is much less than in direct water cooled version. That reduces the complexity and cost of the water systems and reduces the risks. The water systems could probably be completely independent of the radioactive water systems of the main dumps. A peripherally-cooled metal dump would permit a cleaner solution to designing a sharp aperture covering the doughnut shape without compromising water flow or having issues with the material thickness at the inner edges (container walls).

- Detailed design: The detailed design of the doughnut collimators needs work to optimize the length, shape, and materials (Al or Cu), and to evaluate the effect of the spray from the collimators on nearby and down-beam components. The collimator 3PC3 at SLAC located down-beam from End Station A is a doughnut shape with circular aperture about two meters long, designed to prevent spray from beam on targets in ESA from striking the beam pipe to Beam Dump East. It is a water-cooled Al ball design. The shape was optimized with simulations that showed it was more effective if the front water cooled section that absorbed the main power was followed by a second water cooled Cu section down beam with larger radius to catch the spray from the front section. This maximizes the efficiency for interrupting the primary incoming beam and partially eliminating the spray from electromagnetic showers that emerge into the beam pipe from the inner edge that would otherwise the make trouble on the down stream beam pipe. The collimators would probably require at least a meter or more each of beam line z space, and it is not clear that that space is provided in the RDR extraction line design.
- Background Generation: There is a potential difficulty with background from the doughnut COLW1 located just up-beam of the first sweep magnet and just down-beam from GAMCAL. It is possible that back-scattered spray from COLW1 will interfere with the GAMCAL detector.
- Radiation Spray: The radiation down beam from the doughnuts COLW1 and COLW2, together with the deflections of lower energy particles in the sweep magnets, may lead to unacceptable radiation levels on the beam pipes between the sweep magnets and the doughnut COLW3 just in front of the dump. Possibly the beam pipe will need to be shielded to suppress radiation into the adjacent beam line. It is also possible that the COLW1 and COLW2 will generate enough radiation that they will need to be significantly shielded to prevent damage to the sweep magnets just down-beam. This will require more space.

12. Detector Neutron Background: The dump and collimators also generates neutron backgrounds that can damage the silicon vertex detector at the IP (by dislocation of silicon atoms that alter the electrical properties of the pixels). Estimates show the integrated dose to be just below tolerable levels (see talk by Takashi at IRENG07, figure below). The design of the dump and the extraction line needs to take into account the production and possible suppression of neutron background at the IP with appropriate arrangement of collimators and shielding. Takashi's background estimates included important neutron suppression with a W collimator and a concrete wall immediately up beam from the dump. This arrangement is inconsistent with the placement of the doughnut collimator COLW3 in Yury's extraction line layout. More work is needed to arrive at a consistent design, including the integration of all the collimators into the vacuum system, and provide for cooling, alignment and shielding. These background estimates need to be double-checked. If the estimates are wrong, or if we include more generous safety factors, then it may be required to redesign the dump line to put in a bend to obstruct the line-of-sight path for neutrons. This would generate a host of new problems. Electrons bend but photons do not so beamsstrahlung and electrons would be displaced from each other at the dump (perhaps in the same vessel with a larger window?). The large energy spectrum of the disrupted beam would be dispersed in a

bend, and require more effort with collimation and shielding, which makes costs and other trouble. If the problem from neutron backgrounds is significant, it must be solved in the original plan, because there is no good way to retrofit the dump line to make a bend after the tunnels are built.



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13. Beam Sweeping System: The fast beam sweeping system is a critical component of the dump complex that is absolutely required to prevent nearly instantaneous destruction of the dump windows. This puts it on the critical list for much serious analysis and design effort to ensure that it works correctly and is reliable.
    - Magnet and Power Supply Design: What is the design of the sweep magnet and power supply system? Are they understood and adequate to the job? How conservative would the magnet and power supply system be? Is it straining to keep the power and rotation rate and therefore more prone to breakdown and trouble (drifiting in amplitude and frequency, over heating, hard to regulate,…), or is it a rock solid system that just sits there and works.
    - Sweep Radius: A critical parameter is the required sweep radius that prevents damage to the windows and boiling of the water. Lew has calculated that 3 cm sweep radius is sufficient for the design optics and beam power, and that agrees with a similar analysis by the TESLA group. This value needs to be double-

checked, and verified that it works for the possible range of beam parameters that might occur from magnet setting errors and magnet failures.

- Failure Modes: What are the failure modes of the sweep system? If the power supply crashes does it die slowly enough and keep sweeping long enough to be detected within one bunch train so the BCS system can react?
- BCS/MPS interlocks: The sweep status needs to be in the BCS/MPS interlock system. How would this be accomplished with high reliability?
- Prototype? There are lots of tricky problems with fast cycling magnets, especially if they are operating at the limits of the design. Do we need to build and test a prototype of the magnet/power supply system?

Projects That Could Become Work Packages

Lets take a first crack at a list of projects that may need to be done to minimize technical risk and costs. As this list matures, with input from our colleagues, it could be fashioned into a list of specific work packages.

Design projects for systems that are understood to be needed and already conceptually designed:

1. Make a complete physics-driven mechanical design of the dump vessel with water flow, heat removal, choice of materials, manufacturing techniques etc.
2. Make a complete physics-driven mechanical-, thermal-, flow-, and radioactive-handling-design of cooling loops, heat exchangers, pumps, filters, etc.
3. Make a mechanical design of the target window and a window changer mechanism that satisfies the many constraints of reliability and performance.
4. Design the sweep magnet and power supply system (being done by other groups).
5. Design the doughnut collimators.
6. Design the location, size and configuration of the dump caverns.
7. Design the dump vessel shielding enclosure.

Analysis projects with the goal of setting the parameters that defines the dump systems

1. Establish the level of reliability required in the design (how reliable is reliable enough?). Establish that acceptable mean-time-to-failure shall be not less than 1 year, 10 years, …, never).
2. Establish the regulatory environment likely to govern dump design features and performance (pressure vessel codes, radiation safety requirements, environmental contamination rules, seismic design codes, OSHA type rules etc).
3. Analyze window materials for strength and lifetime in high temperature shock and high-density electron bombardment.
4. Do a complete analysis of the expected phase space of the beam parameters – bunch charge, spot size, beam position, number and spacing of bunches, and sweep radius that is

possible at all the high powered dumps and identify regions of phase space where the dump windows will fail unless protected by some system.

5. Identify the systems and methods needed to protect the windows in those regions of the parameter space where windows are vulnerable. What instruments are required (ion chambers, magnet field measurements, magnet current measurements, fast beam kill signals, fast kick to the tune- up dump, etc) and what is the required performance of these instruments (how fast, to what level of precision, stability, reliability, etc.)
6. Analyze the potential failure modes of the dump water containment (window burst, weeping, pipe leaks, air contamination, etc) and identify devices and methods to deal with the failure (fast valves, sumps, air driers, etc)
7. Analyze the methods for recovery from containment failures to see that necessary equipment is designed in at the right places.
8. As the systems and configurations get established (e.g. three devices protect at all times) do a complete risk analysis to establish overall failure probabilities.
9. Continue the analysis of neutron background that might damage the silicon vertex detector, and explore ways to reduce the flux (collimators, absorbers in the dump area). Establish with realistic collimator designs whether or not neutrons from the dump are a serious irreducible background that must be avoided by design changes (bend in the extraction line).
10. Do a thorough analysis (by modeling with FLUKA, MARS, etc) of the sources and distribution of prompt radiation from collimators, beam pipes and dump to establish the expected levels that may need mitigation to protect equipment performance (signals) and survivability from radiation damage (electronics, cables etc).
11. Do a thorough analysis (by modeling with FLUKA, MARS, etc) of the expected locations, levels and lifetimes of residual radiation to aid in designing for access for inspections, maintenance and repairs. Identify potential problems with activation of critical equipment (magnets, movers, sensors, safety equipment, etc). Look for clever ways to minimize residual radiation.
12. Do an analysis of the vibrations produced by the cooling water flow and mechanical systems to see if they are a problem for stability of the adjacent beam line. If so, what level of mitigation (calm the water flow, move the dump, move the pumps, add absorbers) might be required.
13. Work with the designers of the BCS and MPS systems to evaluate the needs, performance and options for instruments and electronics that will be desirable or required to prevent dump failures (instruments and logic for detection and action for magnet failures, beam excursions, dump systems excursions - water, pressure, vacuum, etc). Establish the design philosophy (software in the loop or not, how many devices are needed, how fast do they act, what is the logic?)
14. Analyze the installation scenarios for the major dump equipment in the cavern in conjunction with installation scenarios of the nearby beam lines.
15. Analyze the scenarios for maintenance and repair taking into account radiation sources and required cool down times. What equipment would need to be inspected, and possibly replaced, how often, and how long would it take to get access and do the work? This could impact physics productivity if not carefully thought out.
16. Analyze the potential for beam induced boiling in the dump water. Continue the analysis of possible problems from beam induced pressure waves in the water.

17. Reassess the RDR preliminary concepts to see if larger design changes may be needed to ensure windows do not break, such as moving the dump farther from the IP, putting more active and passive components in (beam expander, more quads, …).
18. Analyze the dump cavern and systems for compliance with typical OSHA type rules: access, egress, noise, lighting, confined spaces, required stay-clear (for cabinet doors, power panels), electrical safety (access to panels front and back, grounding), etc.
19. Analyze the hoist and rigging requirements (weight capacity, coverage, hook height) for installation, and for maintenance and repairs and specify the parameters for any cranes that may be needed.
20. Analyze the expected lifetime of major components that would be difficult or costly to repair (dump vessel, major piping system, pumps, pressure tanks, etc) and think about what would happen if it were necessary to remove and/or rebuild them.

Hardware and software prototyping projects that may be needed to establish feasibility or preferred solutions.

1. Design and build a prototype of the dump window and changer and test it.
2. Design and build a prototype of the sweep magnet and power supply and test it.
3. Make damage tests of potential window materials in high intensity electron beams. Test for strength after irradiation. Look for potential failure modes (modification of alloys by dislocation and temperature shocks, formation of cracks, erosion, etc)
4. Make measurements of backward neutron production and SLAC BDE to compare with modeling codes (FLUKA, MARS), and verify the reliability of the neutron background estimates. (Note, not sure about this one.)
5. Build a complete model of the dump cavern and systems in 3-D CAD for use in analyzing mechanical problems and for input to radiation and vibration modeling codes.

Pictures of SLAC Beam Dump East and Equipment Room


DANGER
HIGH
RADIATION AREA
PERSONAL & SUPPLEMENTAL
DOSIMETER REQUIRED
CAUTION
CONTAMINATION AREA


15°