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A. Introduction

This outline is prepared for the use of any division (or anybody) in CDG interested in transportation of materials or finished products to be installed in the tunnels, shafts, or experimental halls. As an example with large cost consequences we consider the main ring dipole magnets, and make only passing comment about other entities. This is only an outline, and the information applies only to mid 1988. At this time, there are seven prospective sites on the Best Qualified List (BQL) whose characteristics are known to DOE, but not to CDG. The locations of the sites are, however, known to both, and this is all the information needed in this outline. I hope that the information will be broadly useful in design work, planning, and decision making.

1. Current dipole properties

The dipole magnets are an ideal focus for discussion of transport requirements: they are bulky (especially longitudinally), heavy (dense), fragile (suspension of the cold mass by composition posts), awkward to load, (can't use standard forklifts), ship (can't use standard length truck trailers), and emplace (don't fit horizontally within standard size shafts), and indispensable. As a model, I consider the 7664 (3832 per ring) of the 16.54 m bending length dipoles specified in "The 90 degree (September 1987) SSC Lattice", by A.A. Garren and D.E. Johnson, Report SSC-146. As shown in Figure 4 of that report, the actual machine length of the six dipoles is 17.34 m due to the 0.8 m separation drift space between them. With shipping restraints, the shipping length will probably be around 18 m. The effective mass/weight of the 17 m dipole is taken to be M1 = 22,800 lb = 10,342 kg = 10.34 tonne = 11.4 (short) tons, from a recent measurement at Fermilab (27,600 lb - 4800 lb for lift fixture). At the tunnel/cryostat meeting of 6/2/88, Ralph Niemann (FNAL) gave the weight (mass) of DD0014 as 22,240 lb (10.088 tonne). The cold mass for the long dipole is officially 6759 kg; pp 144-5 of the CDR Magnet Design Details (Attachment B) also list values of 7250 kg and 7144 kg for the cold mass. According to Bob Kehl (BNL), the weight (mass) of the cold mass including 200 lb of end valves is about 15368 lb (6971 kg). At this time, it seems unlikely that the target transportation weight of 21,500 lb (9752.2 kg) will be reached in the current test series. (This weight is the break point for shipping two magnets per load instead of one).

2. Design environment accelerations and frequency response.

The fragility of a load can be defined in terms of the acceleration the load can withstand without its essential characteristics being changed (e.g. without breaking). As an example, the dynamical design environment given in Attachment B of the CDR on p 145, Table B.13-4, lists transportation and handling acceleration limits of 5 g vertical, 3 g axial, and 2 g lateral; for these specifications, shipment by rail might become practical (see below). These specifications assume that full length brace and end cap restraints are affixed to the magnet for shipping and handling, and are removed after the dipole is emplaced on its stand in the tunnel. The full length brace design was interior to the cryostat, but this has been removed from the interior in recent designs. The current design environment states that the dipole should remain unaffected by accelerations of 2.0 g vertically, 1.5 g axially, and 1.0 g laterally applied as impulses over times of 2.0 ms to 84 ms. This design environment corresponds to motion without restraints. The cold masses would have higher natural vibration frequencies omega = SQRT(k/m) with respect to their mounts if they were lighter or more stiffly mounted; standard structural engineering practice tends to shift the frequencies of the lowest vibration modes upward to reduce excitation, the reasoning behind the stiffeners (collars) installed on recent dipole cryostats at Fermilab. These 1" steel collars greatly increase the mass of the dipole as they also stabilize the piggyback over/under mounting system of the dipoles. With the change in design from the piggyback mount to emplacement of both magnets on stands, the collars could be reduced in size and the form of the collars and support feet altered to match the conditions of stand mounting. They could be squared off in outline to give greater resistance to torsion in shipping and handling, and serve as regions of attachment of hoist rings or/and lift fixtures. This would also serve to improve stability and ease of mounting on the stands into which they are emplaced within the tunnel. The upper and lower surfaces should allow for the insertion of forklift tines and the upper rings or loops should accommodate crane hooks. Because the dipoles are topheavy (see design picture), they are hard to handle with slings; the extra time required for safe rigging will drive up labor costs. No current shipping restraint designs exist; suggestions range from simple screw on end caps to keep dust out to turnbuckled bars extending the interior length of the beam tube . The end caps themselves can provide some support to the cold mass by the way they enclose it and fit around the cryostat.

B. BQL Site to Supplier Distances- Table 1.

Table I lists mileages between the BQL sites and seven potential magnet suppliers. The states between the source and the site are also given, to enable the cost of special permits (see below) to be calculated. The routes are mostly in the range of 350 mi to 2500 mi, and the averages are 737-1677 mi; the mean of the averages is 1155 mi. In section 7.2.2 (p624) of the CDR it states, "The fabrication and installation of the main collider ring magnets have received considerable attention during the planning studies. The magnet production plan is based on the assumption that two or more industrial firms will manufacture the nearly 8000 magnets required and ship them to the SSC site for final testing and installation. The peak production rate of approximately 600 dipole units per quarter [2400 dipoles/year = 46 per week, a little over 9 dipoles per 5 day work week] requires an efficient and aggressive work plan". Alternatively, a supplier might avoid some trucking costs by constructing the magnet production facility on site or in the nearby metropolitan industrial area; this will be called the local production model. The local production model avoids problems associated with the need for high cost shipping of finished articles that are sensitive to accelerations associated with transport, by using low cost transport of raw materials insensitive to acceleration. Two of the cases in Table 1 correspond to the local production model. Quotes have been obtained for rail shipment of 1) the raw materials (steels) on flatcars; 2) the finished dipoles on air ride flatcars at the applicable tariff rates from Southern Pacific. For steels, the cost per lb for transport from Los Angeles to Phoenix is $0.0222 (80,000 lb minimum load)(tariff reference PSFB 3726, item 4270); from Los Angeles to Dallas, the cost per lb is $0.0599 for 90,000 lb minimum load, and $0.0571 for 120,000 lb minimum (tariff reference TCFB 3002, item 8170). For finished magnets, class 40 rate, the Phoenix cost is $0.0679 per lb (UFC 6000, item 63260) and for Dallas the cost is $0.1445 per lb both cases shipping from Los Angeles with a 30,000 lb minimum load. So the cost of finished magnets (assuming they could be shipped by rail) is about 2.4 to 3 times the cost of shipping the raw materials (see also part D). The cost of shipping either materials or magnets under a contract arrangement for large scale transport would be much less than this (see estimate in C.3 below), but the relative costs would probably be similar.

C. Modes of transport

1. Air

Flying Tiger Airlines is the only domestic carrier I found that would handle the dipoles. For flights taking off late one night, getting in early the next morning, this runs around 24k$ per flight. With a 14 ton effective weight limit, this means only one dipole per flight. (SFO, 877-3111).

2. Water

The northern and eastern sites are less than 140 miles from barge or deepwater transport, and the Illinois site is only 45 minutes away. For the three western sites, the nearest such ports are within a day's drive. For specialized large size components (detector iron) water transport may be effective on occasion. Typical items transported in this fashion include unfinished items such as grain, ores, metal stock, lumber, and hides. Exclusive of storms, docking maneuvers and loading, the peak accelerations may be low. Because the magnets are critical path items that need to be installed as rapidly as they can be built, the expense of controlled storage, etc., it is usually assumed tht magnets will be shipped to a point on site soon after manufacture. Because of the small numbers of magnets to be transported per unit time (10 per day at peak manufacture) it is usually assumed that water transport is not practical. Also, since a given magnet will have to travel at least a portion of its journey by rail or truck, an extra step of loading and unloading must necessarily occur.

3. Rail

All the BQL sites have railroad access to some point near the site, but not necessarily to the campus area. However, moving the magnets by rail is impractical because of the large longitudinal accelerations that occur in making up a train (humping the cars) and in travel up and down steep grades. Typical impulse loadings found during transit can range up to 3.7 g in the longitudinal direction, 0.3 g side to side (laterally), and 1.7 g up and down (vertically), for a hydrocushion suspension flatcar, 89 ft piggyback design. Regular suspension flat accelerations run higher. One cannot attach a suspension frame onto a hydrocushion or other special suspension trailer, as resonances may occur. A special frame would have to be loaded onto a standard suspension car, which would see 5 g or more. Experienced train operators can reduce the loading to a marked degree, however this may substantially increase the cost. Mountainous routes should be avoided, as the greatest longitudinal forces in transit are produced from slack action. Loading in the yard, called humping (which is done to compress the train string), gives forces much larger than those experienced in transit. One would arrange for special handling to minimize this, as well as placard the cars with DO NOT HUMP signs for extra insurance. Impact meters are commonly used to verify that loadings have not been exceeded; however, they monitor higher overall levels than the dipoles can tolerate. The cost of a 140,000 lb capacity flatcar with hydrocushion will run about 2k$ per load, special handling, for a 1000 mi trip. Note that six dipoles (136,800 lb) could be shipped on such a flatcar, provided that they could withstand the accelerations. This works out to 2k$(7664/6) = 2555k$ = 2.6M$ total shipping costs via rail. The improvement of axial acceleration response is therefore an important design consideration, as it can lead to significant cost savings in transport.

D. Trucking of magnets to site: hiring a trucking firm to do it. Permits.

The following information is from a couple of phone calls to a representative nationwide longhaul truck firm, WERNER Specialized Carrier of Omaha, Nebraska; General Offices, (402)895-6640. The information was verified in a conversation with Jim Werner on 4/29/88. Shipments are based on a 60 ft load occupying a two axle flatbed extending trailer, 4.75 ft high, 60 ft extended length, 40 ft closed length. The additional load capacity is 43,000 lb (makes gross vehicle weight up to Interstate limit of 80,000 lb). The company has two such trailers in its fleet; their use in longhaul loads is not common within the industry. A maximum liability of $100,000 per load is allowed. The base rate of $1.05 per mile has an additional charge for the long load of $0.35 per mile for distant origin destination pairs such as Boston/Chicago, Boston/Dallas (1737 mi), Boston/Denver (1946 mi), San Diego/ Denver, and so on; for short runs, like San Diego/Phoenix, a minimum charge of $400-$500 is made, so the mileage charge is $1.40/0.35 for this run. A more standard (not long) flatbed trailer would have dimensions 8.5 ft wide by 48 ft long and would accommodate a 48,000 lb load. The $1.05 per mile rate for the shorter flatbed trailer might be even less, subject to negotiations on the costs of repetitive trips as opposed to a single trip. Again, a minimum charge would be imposed for short hauls. Permits for long loads run from $5 to $25 per state where necessary, and escort (pilot cars) costs run $0.80 to $0.95 a mile where required. (None of the BQL states require escort service for loads of less than 75 ft overall length). The shorter trailers, being more common, would always be available; the longer trailers are less numerous in any truck fleet, and might be subject to seasonal demand.

As an example, let us consider the shipping costs associated with the "average average distance", 1155 mi. In addition to illustrating the costs of shipping the 17 m magnets or just the raw materials, I take the case of a set of shorter and more numerous magnets to illustrate the effects of the extra length on transport. As a comparison model, I take the case of an eight for six increase in the number of dipoles in a half cell, which would give each of the eight dipoles a magnetic length of .75(16.54m) = 12.405 m. If the drift space is scaled to correspond, the actual length of the (currently hypothetical) short dipoles would be .75(17.34 m) = 12.405 m + 0.600 m = 13.005 m = 42.667 ft. The short dipole weight/mass would be M2 = .75(22240 lb) = 16,680 lb = 7565.92 kg = 7.56592 tonne = 8.340 short tons. A 60 ft trailer for the long dipoles has an interstate load capacity of 43,000 lb; a 45-48 ft trailer for the short dipoles has an interstate load capacity of 48,000 lb. The long trailer can therefore carry only one long dipole (2x22240=44480>43000), whereas the short trailer can carry two short dipoles (33360<48000). In contrast, a full 48,000 lb of raw materials could be transported. It is possible that the raw materials might be shipped at less than $1.05/mi after negotiation, but I take the full value for the time being. For a given 1155 mi trip, the 7664 long magnets are costed at $1.40/mi plus $35 of permits; the 10219 = (4/3)7664 short ones are shipped at $1.05/mi. This corresponds to shipping costs of 7.27068 cents/lb for the long dipoles, 3.63534 cents/lb for the short dipoles, and 2.52656 cents/lb for the raw materials (assuming no wastage). The total costs for moving the 172.67 M lb by truck turn out to be 12.554 M$ for the long dipoles, 6.277 M$ for the short dipoles, and 4.363 M$ for the raw materials. Compare this to the 2.6 M$ for contract rail shipment given above. Other things being equal, it looks attractive for a potential magnet supplier to build

and test the dipoles at a railhead on or near site, since no such factory currently exists. Other factors such as skilled labor forces and unused plant capacities would certainly be considered by a prospective supplier, but this estimate shows the cost breaks expected for transport. It also highlights the general importance of having a rail spur near the campus area, since many components (such as detector iron) may be sized so that interstate truck transport is not possible.
Permits and restrictions for the BQL States:
Unless stated otherwise, the distance of front bumper to rear of trailer is assumed to lie in the length range between 65 ft and 75 ft; no escort is required in these states. The January 29, 1988 Federal Register contains the change in overlength requirements to be a trailer length of greater than 48 ft, independent of length of the tractor. A grandfather clause will allow states with greater overlength distances for trailers (such as 59.5 ft in Louisiana) to remain in effect for a few years. The result is that overlength on single trailers is governed by the 48 ft standard nationwide, in that no permits are needed for loads of less than that length. Thanks are due to Don Massy for calling this to our attention. This was verified via the U.S.D.O.T., (415)974-7006.
Overlength permits and restrictions are as follows.
Golden Rule of Permits: No state will give a permit for a load that can be made legal. Example: One cannot have more than one object on a load and obtain an overweight load permit.
AZ: $15 oversize permit required, obtain at port of entry.
CO: Move trailer length in to less than 70 ft front bumper to end of trailer and let load overhang less than 15 ft to make a legal load; no permit is then required.
IL: Exempt from permit, but long load travel is daylight only, Monday through Friday.
MI: $5 permit required.
NC: $5 permit required; less than 15 ft overhang allowed.
TN: No permit needed for less than 75 ft load.
TX: $20 permit ($21 for credit card operation with self issue forms; Visa, Mastercard, PAC cards; the entire operation can be conducted by phone/mail) required for oversize loads.

The foregoing assumes that the 80000 GVW and individual axle ratings (bridge law) are not violated.

E. Trucking the cold masses from Brookhaven to Fermilab

Some firsthand experience in moving SSC equipment comes from the shipment of individual long magnet cold masses from BNAL to FNAL. The following information was provided by Steve Plate (FTS 666-4475). The cold mass is fixed to the bed of an extendable 40'-60' air ride trailer at four points chosen to move the frequency of vibrations of the lower modes to as high as possible. The cold mass itself is fastened to a reinforcing beam shipping restraint (strongback) and both are packed in a styrofoam lined wood and aluminum box. Auxilary equipment allows the box and cold mass to be air conditioned (cooled) in transit. (x,y,z) strip chart recorders obtain continuous records of accelerations in the vertical (Z), lateral (across the trailer, X) and longitudinal (in the direction of travel, Y) directions. In the first two trips, typical rms accelerations in the vertical direction were about 0.3 g and were about 0.1 g in the lateral and longitudinal directions. Adverse weather conditions of uncleared snow and ice on the road during the first trip gave maximum vertical accelerations that exceeded the scale on the accelerometer of more than 2.1 g; the maximum lateral acceleration was 1.3 g and the longitudinal acceleration did not noticeably differ from the rms value. On this trip, the maximum vertical acceleration occurred over the wheels. On the second trip, it was recorded near the center of the load. The maximum acceleration on the second trip was 2.0 g for vertical accelerations near the center of the load and 1.0 g for the lateral accelerations; the longitudinal accelerations were still down in the background. The weather condtions for the second load were such that the roads were cleared and dry. The route followed the Long Island Expressway from BNAL to the Clearview Expressway over Throg's Neck Bridge to the Cross Bronx Expressway, across the George Washington Bridge to I-95, and from there to I-80. The remainder of the route basically followed I-80, except for the portions on IL 5 and then Farnsworth Road near FNAL.

The transport costs for this operation were kindly supplied by BNAL. The transporter was New Breed Moving Corporation ((516)586-2535) of Deer Park, NY. Charges for the transport of the oversize trailer one way were $1900 ($1900/850mi = $2.235/mi) plus $200 for supplying generator power and a 4% surcharge of $160, for a total of $4160 to ship the magnet coldmass to FNAL and bring the trailer back. The price includes an air ride tractor, permits, checking and servicing the air conditioners, and a day layover due to overlength restrictions and total time over the road. Unless there are some details of which I am not cognizant, the trailer should have been compressed to 40 ft before the trip back to avoid the overlength charge. Similar charges provided by the Fermilab Receiving Department list costs for a 45 ft trailer of $1,532.16 if the truck can take a load of freight on the leg in which it is not transporting the cold mass, and $2,197.12 if the truck/trailer has to deadhead back (return empty); the corresponding figure for a 60 ft trailer is $2,184.00 with freight, and the deadhead option was not provided. (2184/850 = $2.57/mi)

F. Trucking of magnets to the site: doing it ourselves.

There is general agreement that a new double rear axle tractor is in the 30k$ price range. A call to Fruehauf (415)569-3331 elicited the information that a 42'-65' extendable flatbed trailer with air ride suspension and radial tires would be around 20k$. For purposes of calculation (+10%,-5%) the price of a tractor/extension trailer combination will be taken to be 50k$. It will further be assumed that during peak production of dipoles, there will be 10 per day (50 per week) produced by the industrial supplier that must either be stored in rented space or trucked directly to the site. For purposes of planning, assume that the distance between source and supplier is about 1250 mi, around the average value found from Table I. That gives an effective two day haul from supplier to site. If we assume that the return trip takes a comparable amount of time (and then the driver gets two days off) we get that one driver can pick up one magnet per week, so we will need 50 truck/trailer combinations and 50 drivers to transport the 50 magnets. A fulltime LBL driver would probably START at between $14-$16 an hour; at $15/hrx40hr/wkx52 wk/yr = $31200/yr and a multiplier of 1.4 for the benefits package, this is $43,680. We round this to 50k$, since some of the current drivers are making an average of $17.23/hour = $50173.76/yr including the benefits package multiplier. This means that our fleet cost of 2.5M$ is the same as the cost of our drivers for a year. A 2(1250) = 2500 mi round trip with a truck getting 10 mpg for diesel fuel costing $1/gal costs about $250 per trip in fuel. For three days at $60/day and one day at $30/day, (CDG allowance) there is a per diem driver expense of $210 per trip. An additional $40 per trip for overlength permits brings the cost of fuel, permits and driver expenses to $500 per trip. Since the trucks are purchased new (under warranty) and amortized to zero over the time to transport the magnets, we will not add any *maintenance* costs at this point. Because of problems in scheduling, the time over which the transport takes place will be taken as *five* years. If *efficiency* is *high*, perhaps 50 trips/wk in 50 weeks/year = 2500 trips per year can be made. To first order, our yearly costs will be as follows:

$500/trip expenses x 2500 trips	= 1.250 M$/yr expenses
50 drivers x 50 k$/yr	= 2.500 M$/yr salaries
amortized fleet cost 2.5M$/5	= 0.500 M$/yr equipment
subtotal	= 4.250 M$/yr

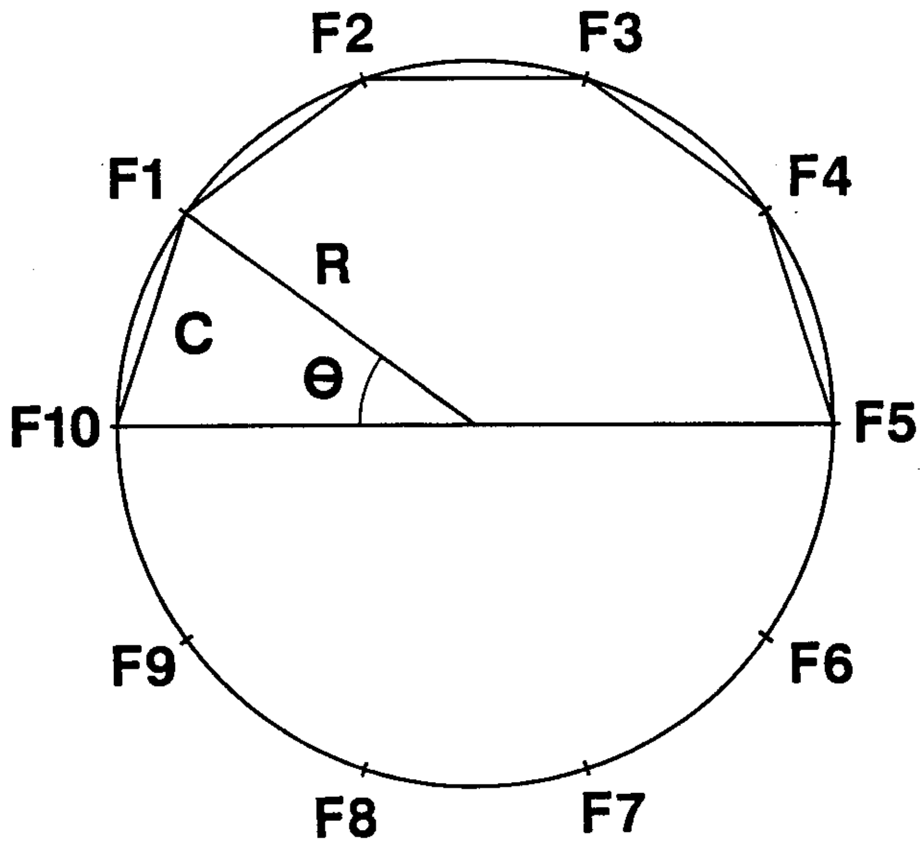
cost per trip is 4.25M$/2.5k = $1700 per trip = $0.68 per mile. Against this rosy scenario is the probability that many of the drivers would wind up being retained by the lab owing to seniority; maintenance of the fleet, a potential big ticket item, is not included; insurance, taxes, licenses, and miscelaneous fees are not included. Assuming that insurance is 8% of the new unit value per year, this is 0.200 M$/yr; from signs on the rear of trucks reading "this vehicle pays $xxxx in road use taxes", taxes and licenses will be taken as 4k$ per year per unit, or 0.200 M$/yr. As a wild guess, the cost of maintenance and equipment replacement beyond that covered by warranty will be taken as 10% of the fleet cost, or 0.250 M$/yr. This would give an estimate of the total cost of around $4.9 M$/yr. The cost per trip is then 4.9 M$/25k = $1960 per trip = $0.784 per mile. (Note: at $1.35/mi(1250 mi) = $1687.50, if Werner can get return loads, so that they just charge us one way mileage, they can beat the cost per trip). Assuming that the SSC is a nonprofit operation, we would not be able to transport return loads, and would therefore have to deadhead back.

G. Trucking magnets around the site

A good working relationship with the local community is vital to this phase of the operation. With the extra long trailers, the trucks will not be able to smoothly negotiate roads with a 50 ft corner radius of curvature at a 90 degree bend. (See, for example, A POLICY ON GEOMETRIC DESIGN OF RURAL HIGHWAYS, AASHO, 1965, pp 318 and 325). One of the ways of minimizing this phase of the problem is to maintain temporary storage facilities at each shaft head through which magnets are to be installed, and have the trucks from the factory unloaded at these locations. This is the direct factory to shaft model of trucking. The more usual plan is that the magnets are trucked from the factory to an onsite test/distribution facility and dispersed to the shafts via truck. In this case, considerations similar to those above would apply in terms of cost per mile, but many more magnets would be shipped per truck/trailer/driver combination.

A generic model of the local transport of the dipoles was developed in order to define minimal parameters relating to costs, times and equipment aquisition. The dipoles are to be installed via the service area shafts. As a model of the site road network, I choose the 10 equally spaced points on a circle that could inscribe a site to represent the shafts, and the connecting chords to represent the ring road network. All the sites have some system of roads to the service areas that extend a somewhat greater distance the chord system, so the numbers below are an underestimate; however, the model adapts easily to different parametrizations. Since the system is symmetric, one need consider only one semicircle and its inscribed chords. The road system is chosen to lie along contiguous chords and a diameter.

A chord of a circle $C = 2R \sin(u/2)$ subtends an angle u at radius R. For 10 service areas, $2\pi = 10u$. Thus, $C = D \sin(\pi/10) = D \sin 18^\circ = 0.309017D$, about $\pi D/10$. The shortest path to the first n-1 service areas is via the chords, but eventually it pays to cut across the diameter and double back to reach the nth service area. The latter path is shorter when $(5-n)C+D<nC$, or $n>(5C+D)/(2C) = 4.1$ in this example, so only the area diametrically opposite the campus region is accessed by the road along the diameter. Let the service areas be labeled in the same sense as in the ISP (see illustration). If the number of dipoles inserted per service area shaft is N, then there are only N trips required through or to service area F4 at a distance of 4C; to/through F3, there are 2N trips at a distance of 3C; to/through F2, there are 3N trips at a distance of 2C; to/through F1, there are 4N trips at a distance of C. If one multiplies the number of trips times the distances, there are $4NC+6NC+6NC+4NC=20NC$ distance of travel for the upper semicircle, or 40NC for the circle. There will be N trips along the diameter to shaft F5; all trips are taken to originate with shaft F10, for which no distance of road travel is allowed. The total distance traveled to all shafts is $L = 40NC + ND = 13.36\,ND$. For the dipoles only, N = 767 trips per service area. The inscribing


F2
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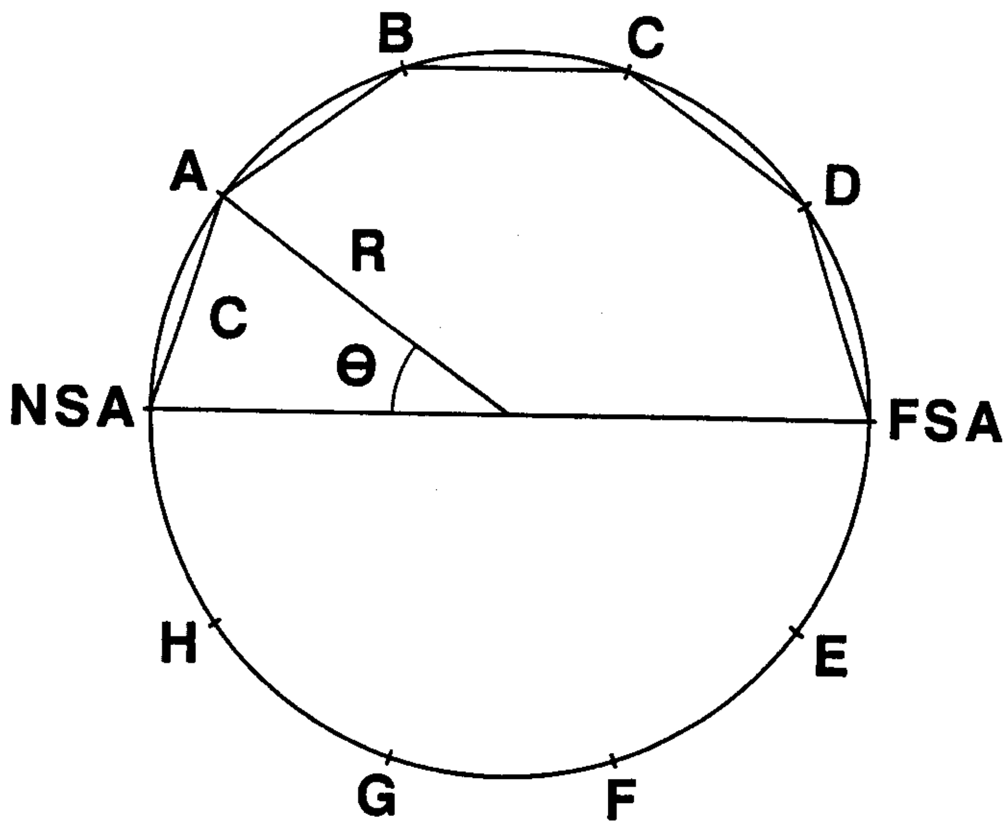

SSC CENTRAL DESIGN GROUP	
TITLE. COLLIDER RING TRANSPORT MODEL LOAD THROUGH SERV. A. SHAFTS	DRAWING NO. BIC33
DWN. BY: REV. DATE	
APPR. BY: / D.G DATE 8-15-88	DISK.

circle has a diameter of about 18 mi, so L = 13.36(13806) = 184,448 mi. The distance to F4 is 4C = 4(0.309017)18 = 22.5 mi. If loaded trucks proceed at an average speed of 33 mph, this corresponds to a time spent of 0.03 hr/mi, so it takes about 2/3 hr to get to F4 from F10. If it takes 1/2 hr to unload the dipole from the truck at the service area (see below), then it will take about 11/6 hr per round trip, and a single truck can make three or four trips a day. Three operational trucks should suffice for our local fleet; that would give a figure of 61,483 mi/truck during the installation phase. The assumptions above give a total travel time of dipole delivery of about 5600 hours. By taking two magnets per load, the cost of delivery could be halved (brilliant!). The long load problem: if a $20 permit is required for each long load trip, then it costs 7664($20) = $153,280 in permits to dispense the magnets locally.

H. Details of handling, hoisting, and loading: cranes and lifts.

1. Handling at factory;loading on truck

Handling is a hazard to delicate objects, and the dipoles are no exception. It is assumed that the magnets are constructed in a single building, at the supplier's location or on site. After a magnet has been packaged in its cryostat, it will be moved around within the factory by crane and/or forklift. It is assumed that the cryostat collar is provided with steel loops on the top and that the feet are spaced so as to allow lifting by either top or bottom surface; the collar should be squared off on the base and have a space provided where the tines of the lift fork may be inserted. Flat regions or channels for the forklift tines are especially important for the dipoles, because they are topheavy and should be carried upright insofar as possible. Forklifts with capacities of up to 80000 lb (40 ton) are readily available, although forklifts of up to 25000 lb are commoner; they can be modified to handle the wide spacing of 20-30 ft between the loops or base pickup region on the cryostat. Boom trucks of capacity 2-17 tons and hydraulic portable cranes of 2-300 ton capacity are readily available. Bridge cranes with similar capacities are also common. (Source: Oakland Yellow Pages, Contractor's Equipment and Supplies-Renting) Some preliminary testing and quality checks will be carried out at the factory. The dipoles will then be arranged for shipping. End restraints that constrain the motion of the cold mass will be fastened to a longitudinal support/lift fixture (strongback), so that the internal structural support no longer depends on the composition posts. As a topic of engineering design with large cost payoff, the shipping restraints have high priority (see rail shipment, above). The dipoles are then emplaced on the flatbed trailers or rail cars and fastened (probably bolted) to special motion isolation pad fixtures firmly mounted on the flatbed; additional restraint can be provided by multiple steel straps that are typically used to tie down heavy loads. It is assumed that the magnet components are thermomechanically stable to temperatures of 50 C, so that covering the load with a tarp provides sufficient protection against ambient temperature extremes and moisture. An air conditioned enclosure might have to be used if the temperature requirements on movement are too severe for routine handling; this will boost transport costs by an extra $200-$300 per load for generator service (see above) and enclosure materials and fittings.

2. Unloading at test facility; reloading for trucking to service area

The dipoles are shipped by truck or rail to a magnet test facility in the standard scenario; they will be unloaded by crane or forklift. They will be emplaced on a test stand and the lift fixture removed, and undergo whatever testing is necessary at this point. If they have not been sorted by field variation (CDR, pp133-136) at the factory, this operation is performed at this point in the flow. The lift fixture is then reinstalled, and the dipole loaded onto a trailer to be conveyed to the shaft head at a service area. Depending on whether the sorting of the dipoles is carried out at the factory or on site, it might be feasible to store some of the dipoles at the service areas in temporary buildings. That is, the load would be trucked directly from the factory to the service area. This would reduce the number of handling operations of loading and unloading and save campus to shaft transport costs. Tests of entire strings might preferably be made in the finished tunnel positions, so that there would be no necessity of unwelding (cutting) the ends. If the dipoles are manufactured, tested, and sorted on site, the transport process begins at this point. The dipoles are then trucked to the shaft heads at the service areas.

3. Lowering through shaft or slot at service area to tunnel depth

The next two sections rely heavily on the excellent summary by Derek Shuman, "Sector Service Areas" (SSA), SSC-N-470, pp6-10. At the service area, the dipole is removed from the trailer using a portable crane. A 15 to 25 ton capacity will be required, depending on the shaft depth. The ends of the shipping fixture are then arranged with small wheels fitting into guide rails of a circular shaft; the dipole is lowered at a steep angle (about 60 degrees) until it reaches tunnel depth, where a boom reorients the magnet in a horizontal position. Alternatively, a double crane simply lowers the magnet horizontally through a rectangular shaft. The final step in either case is that the dipole is gently lowered to transport position on an electric magnet transporter. A closed circuit TV camera at the base of the shaft allows the crane operator to lower the dipole in place without the hazard of having personnel in the shaft below during this operation. Radio contact with personnel in the shaft tunnel nearby (out of the way!) will supplement this observation. Control of the last part of the lowering process from the shaft tunnel is also possible.

4. Movement by magnet transporter through tunnel;emplacement
 The electric powered magnet transporter has backup batteries, but normally takes its power from a shielded "third rail" mounted along the tunnel wall, like a trolley car. It has steering units on each end for bidirectional travel in the narrow tunnel space. The supports for the dipole could be hinged in such fashion that they serve as a forklift that swings over the top of the transporter; similar devices are used to emplace precast concrete liner in tunnels. The transporter could have extensible leg braces that allow the dipoles to be lowered to floor level without tipping the transporter. Alternatively, the magnets may be unloaded from the transporter and then positioned by an electricly powered forklift designed to operate within the tunnel. This keeps the transporter from being tied up during the time of position adjustment. The limitation in this mode of operation is the available space between transporter and wall in which the forklift would fit. I personally favor having the transporter unload the magnet at its approximate position on the magnet stand and have it realigned by the survey crew with readily available hydraulic devices. The dipoles are placed atop and beneath racks oriented in approximately the correct position with respect to local survey markers. Mechanical positioning by bolt settings and insertion of shims accompanies the final optical alignment, and allows minor corrections after alignment using the beams. The horizontal movement on the stand surface and the vertical movement constitute sufficient freedom of orientation.

I. Conclusions and Recommendations

1) The fragility and excessive size (length and mass) of the dipoles as currently designed are expensive. If the dipoles were not fragile, they could be shipped by train. If they were not as large, they could be shipped on shorter and commoner trailers (see below); if they were lighter they could be shipped two to a trailer rather than one, a factor of two difference in shipping costs.

2) From the facts that no factories for the production of SSC magnets currently exist, that shipping raw materials is 2.5-3 times cheaper than finished dipoles (even if both are sent by rail!) it can be deduced that it will usually pay a potential magnet supplier to construct a factory on site (if buildings and utilities can be made available in time) or in a nearby industrial park. The cheapness of the latter alternative would have to be balanced against the slightly higher driving times and transportation costs to get from the factory to the shafts.

3) In order to avoid having excess numbers of nontechnical laboratory personnel and save on operating costs, it seems that considerable effort should be expended in hiring a reputable trucking company, preferably from the site region

or a nationwide firm based in the middle of the country. While the choice of the Nebraska firm for comparison was merely illustrative, the rate comparisons versus the New York and Illinois firms shows that considerable funds can be saved by judicious choice of the trucking firm.

4) The dynamic response of the dipoles is to be studied by Vibration Engineering, Inc. The results of such tests will be of great importance in the design of shipping restraints (cheap objects with a large payoff for creative design) and any necessary changes to the support system. The trucking of the HERA magnets is proof of principle of the transportability of magnets with composition support of the cold mass, although the suspension system for the shorter magnets of that case is somewhat different. The Avco suspension design shows that it is possible to have robust suspension and low heat leak simultaneously. It is of considerable importance that the dipoles be transported and handled without degradation of performance, if one is to wind up with an accelerator rather than a collection of magnets. A large improvement in resistance to acceleration in the shipping/handling mode is both possible and necessary.

5) Depending upon point of origin, shipment by waterway and then truck or rail may be an attractive option for sturdy heavy objects like detector iron, building materials, cranes, storage tanks, and the like.

6) Handling of the dipoles is a frequent and important step in construction of the SSC; it needs to be done in a way that guards against any deterioration in performance. The topheavy design makes non rotatable forklift and crane hook fixtures highly desireable.

J. TABLE 1. Distances Between Magnet Suppliers and Site Cities

ORIGIN	DESTINATION	DISTANCE (MILES)	STATES BETWEEN O & D STATES
San Diego,CA:			
	* Phoenix, AZ	353	
	Denver, CO	1095	NV,AZ,UT
	Chicago, IL	2093	NV,AZ,UT,NE,IA
	Jackson, MI	2288	NV,AZ,UT,CO,NE,IA,IL,(IN?)
	Raleigh, NC	2566	AZ,NM,TX,AR,TN
	Nashville, TN	1997	AZ,NM,TX,AR
	Dallas, TX	1348	AZ,NM
	AVERAGE	1677	
Schenectady, NY:			
	Phoenix, AZ	2478	PA,MD,VA,TN,AR,OK,TX,NM
	Denver, CO	1816	PA,OH,IN,IL,IA,NE
from	Chicago, IL	801	PA,OH,IN
Albany,	Jackson, MI	719	PA,OH
-15,W	Raleigh, NC	691	PA,MD,VA
+15,S	Nashville, TN	1049	PA,MD,VA
	Dallas, TX	1662	PA,MD,VA,TN,AR
	AVERAGE	1317	

Carteret, NJ:

	Phoenix, AZ	2445	
PA,MD,VA,TN,AR,OK,TX,NM			
	Denver, CO	1794	PA,OH,IN,IL,MO,KS
same as	Chicago, IL	809	PA,OH,IN
New York,	Jackson, MI	729	PA,OH
NY	Raleigh, NC	534	MD,DC,VA
	Nashville, TN	900	PA,MD,VA
	Dallas, TX	1559	PA,MD,VA,TN,AR
	AVERAGE	1253	

Old Bethpage, NY or Purchase, NY:

	Phoenix, AZ	2477	
NJ,PA,MD,VA,TN,AR,OK,TX,NM			
	Denver, CO	1826	
NJ,PA,OH,IN,IL,MO,KS			
	Chicago, IL	841	NJ,PA,OH,IN
NY+32	Jackson, MI	761	NJ,PA,OH
	Raleigh, NC	566	NJ,MD,DC,VA
	Nashville, TN	932	NJ,PA,MD,VA
	Dallas, TX	1591	NJ,MD,VA,TN,AR
	AVERAGE	1285	

Pittsburgh, PA:

	Phoenix, AZ	2087	
OH,IN,IL,MO,OK,TX,NM			
	Denver, CO	1427	OH,IN,IL,MO,KS
	Chicago, IL	476	OH,IN
	* Jackson, MI	376	OH
	Raleigh, NC	508	MD,WV,VA
	Nashville, TN	567	WV,KY
	Dallas, TX	1208	WV,KY,TN,AR
	AVERAGE	950	

Detroit, MI

Phoenix, AZ	2008	IN,IL,IA,NE,CO,NM
Denver, CO	1283	IN,IL,IA,NE
* Chicago, IL	275	IN
* Jackson, MI	80	--
Raleigh, NC	710	IN,OH,WV,VA
Nashville, TN	543	IN,KY
Dallas, TX	1156	IN,MO,OK
AVERAGE	865	

Chicago, IL

Phoenix, AZ	1742	IA,NE,CO,NM
Denver, CO	1021	IA,NE
* Chicago, IL	(local)	--
* Jackson, MI	195	IN
Raleigh, NC	817	IN,KY,WV,VA
Nashville, TN	466	IN,KY
Dallas, TX	921	MO,OK
AVERAGE	737	

* A $400-$500 fee is usually charged for short mileage trips.

Source: 1986 State Farm (Rand McNally) Road Atlas

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