Problem 3 Solutions
Fall, 2002

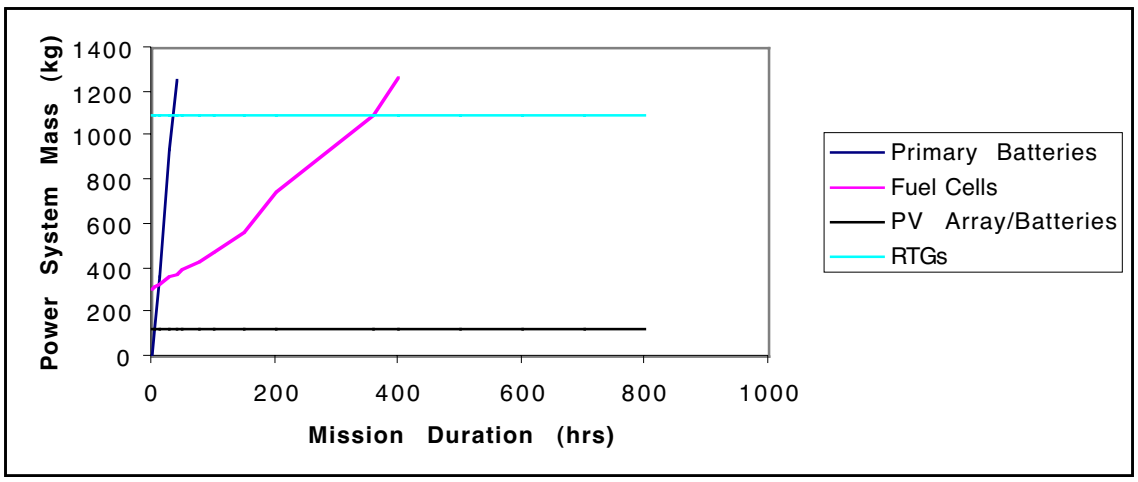
Battery system: Energy requirement is (5000 W)(mission duration in hrs). Dividing this by the specific energy of the batteries (160 Whr/kg) gives the required battery mass as 31.25 kg/hr of mission. (This is going to get heavy, fast!)

Fuel cell system: Based on the cited data, there is a constant installed mass of 115.7 kg for the reactor (which has more capability than we need, but I said to use the shuttle system). The reactants usage is spec'ed at 220A, and (220A)(28V)=6160 W. We need 5000 W, so our application will use (4 lb/hr)(5000)/6160= 1.473 kg LOX/hr (with unit conversion thrown in.) The LOX tank (91.2 kg) holds 354.4 kg of LOX, so every 240.5 hrs of operation we have to add another tank. Similarly, our LH2 usage rate is 0.221 kg/hr, and we need another 98 kg LH2 tank every 189 hrs when its 41.74 kg LH2 capacity is drained. Adding up the four mass sources (reactor, tanks for LOX and LH2, and hourly usage of reactants) gives us a mass/time curve with discontinuities where additional tanks become necessary.

Photovoltaic array plus battery storage: We need sufficient batteries for 44 minutes of operation during nighttime passes. This is 5000(44)/(60)=3667 Whrs of energy, and at a specific energy of 80 Whrs/kg the battery storage system has a mass of 3667/80=45.8 kg. The batteries have to be recharged during the 93min-44min=49 min daytime pass, so the recharge power required is 3667(60 min/hr)/(49 min)=4490 W. The total array power required is therefore 5000+4490=9490 W. At a silicon specific power of 115 W/kg, this gives an array mass of 82.5 kg. The entire system therefore has a mass of 128.4 kg, which is constant regardless of mission duration (ignoring issues like solar cell degradation or limited battery recharge cycles.)

RTG system: The Galileo RTGs have an end-of-life power output of 250 W. Since we need 5000 W, we need 20 RTG units. At 55 kg apiece, the total power system mass is 1100 kg, and is constant with time.

The plor of system mass vs. time looks like this:



The specific cross-over times are:

Battery/PV array crossover – 4.1 hrs
Battery/fuel cell crossover – 11.4 hrs
Battery/RTG crossover – 35.2 hrs
Fuel cell/RTG crossover – 357.5 hrs

You can see that batteries only have very limited optimality, and fuel cells are similarly limited. This analysis uses state-of-the-art photovoltaic array parameters, but (on strict mass criteria) even Shuttle would be better suited to solar arrays. The decision to use fuel cells is often predicated on other criteria, such as not restricting maneuvering or solar angles, or substantially longer dark periods.