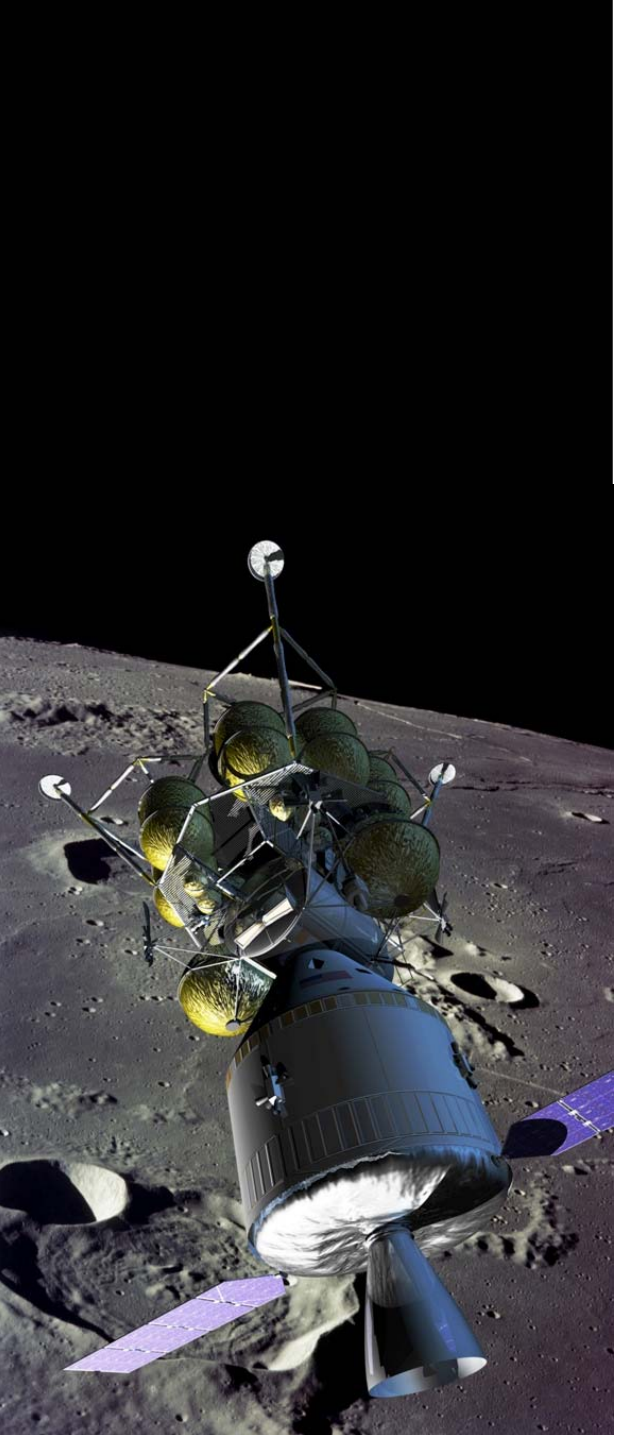

Lunar Outpost Technologies Breakeven Study

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for

SIMA Telecon
NASA Johnson Space Center
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Image Credit: National Aeronautics and Space Administration, Exploration Systems Architecture Study

Study Objectives

- Compare several Lunar Outpost (LO) life support technology combinations
- Evaluate the combinations for two clothing options
  - Disposable clothing
  - Laundry
- Use the Advanced Life Support Sizing and Analysis Tool (ALSSAT) to estimate Equivalent System Mass (ESM)

Study Basis

- Lunar Outpost (LO) on South Polar site at north rim of Shackleton Crater
- Crew of four
- 180-day resupply duration

ALSSAT Notes

- Study used undistributed ALSSAT version 7.0A, which permits a laundry option to be specified for any mission duration
- Water consumption was not subtracted from habitat usage for EVA time
- Primary water processor assumed a cascade distiller system with 93% water recovery
  - specified as VPCAR w/out Air Evaporation in ALSSAT

Sabatier vs. Bosch in ALSSAT

- Sabatier data is for a complete system based on recent development work
- Bosch data is incomplete at this time
  - Does not include CO_2 compressor and accumulator
- Bosch estimates may be low due to other factors
  - Catalyst replacement due to carbon deposits
  - Larger recycle flow impact on other ECLSS equipment

Case Set #1

CASE SET 1	Case 1 - Open Air & Water	Case 2 - Open CDRA	Case 3 - CDRA & Sabatier	Case 5 - CDRA, Sabatier, PMWCL	Case 7 - CDRA, Bosch, PMWCL
Air					
CO2 Removal	CAMRAS (vented)	CDRA (vented)	CDRA	CDRA	CDRA
CO2 Reduction	None	None	Sabatier	Sabatier	Bosch or Sab+CFR
Water Removal	CAMRAS (vented)	Condensing HX	Condensing HX	Condensing HX	Condensing HX
Trace Comtaminant Control	ISS	ISS	ISS	ISS	ISS
Temperature Control	Sensible HX	Condensing HX	Condensing HX	Condensing HX	Condensing HX
O2 Supply	HP Gas	HP Gas	Electrolysis	Electrolysis	Electrolysis
N2 Supply	HP Gas	HP Gas	HP Gas	HP Gas	HP Gas
Water					
Humidity Cond. Recovery	None	VPCAR w/o AES **	VPCAR w/o AES **	VPCAR w/o AES **	VPCAR w/o AES **
Urine Water Recovery	None	VPCAR w/o AES **	VPCAR w/o AES **	VPCAR w/o AES **	VPCAR w/o AES **
Hygiene Water Recovery	None	VPCAR w/o AES **	VPCAR w/o AES **	VPCAR w/o AES **	VPCAR w/o AES **
Laundry Water Recovery*	None	VPCAR w/o AES **	VPCAR w/o AES **	VPCAR w/o AES **	VPCAR w/o AES **
Waste					
Fecal Collection	Simplified EDO	Simplified EDO	Simplified EDO	Simplified EDO	Simplified EDO
Urine Collection	Simplified EDO	Simplified EDO	Simplified EDO	Simplified EDO	Simplified EDO
Water Recovery from Waste	None	None	None	PMWC + Lyoph	PMWC + Lyoph

* If laundry option is selected

** 93% Recovery Specified

Case Set #2

CASE SET 2	Case 1 - Open Air & Water	Case 2 - Open CDRA	Case 3 - CDRA & Sabatier	Case 6 - CDRA & Bosch	Case 7 - CDRA, Bosch, PMWCL
Air					
CO2 Removal	CAMRAS (vented)	CDRA (vented)	CDRA	CDRA	CDRA
CO2 Reduction	None	None	Sabatier	Bosch or Sab+CFR	Bosch or Sab+CFR
Water Removal	CAMRAS (vented)	Condensing HX	Condensing HX	Condensing HX	Condensing HX
Trace Comtaminant Control	ISS	ISS	ISS	ISS	ISS
Temperature Control	Sensible HX	Condensing HX	Condensing HX	Condensing HX	Condensing HX
O2 Supply	HP Gas	HP Gas	Electrolysis	Electrolysis	Electrolysis
N2 Supply	HP Gas	HP Gas	HP Gas	HP Gas	HP Gas
Water					
Humidity Cond. Recovery	None	VPCAR w/o AES **	VPCAR w/o AES **	VPCAR w/o AES **	VPCAR w/o AES **
Urine Water Recovery	None	VPCAR w/o AES **	VPCAR w/o AES **	VPCAR w/o AES **	VPCAR w/o AES **
Hygiene Water Recovery	None	VPCAR w/o AES **	VPCAR w/o AES **	VPCAR w/o AES **	VPCAR w/o AES **
Laundry Water Recovery*	None	VPCAR w/o AES **	VPCAR w/o AES **	VPCAR w/o AES **	VPCAR w/o AES **
Waste					
Fecal Collection	Simplified EDO	Simplified EDO	Simplified EDO	Simplified EDO	Simplified EDO
Urine Collection	Simplified EDO	Simplified EDO	Simplified EDO	Simplified EDO	Simplified EDO
Water Recovery from Waste	None	None	None	None	PMWC + Lyoph

* If laundry option is selected

** 93% Recovery Specified

Case Set #3

CASE SET 3	Case 1 - Open Air & Water	Case 2 - Open CDRA	Case 4 - Open CDRA, Electolysis, PMWCL	Case 5 - CDRA, Sabatier, PMWCL	Case 7 - CDRA, Bosch, PMWCL
Air					
CO2 Removal	CAMRAS (vented)	CDRA (vented)	CDRA (vented)	CDRA	CDRA
CO2 Reduction	None	None	None	Sabatier	Bosch or Sab+CFR
Water Removal	CAMRAS (vented)	Condensing HX	Condensing HX	Condensing HX	Condensing HX
Trace Comtaminant Control	ISS	ISS	ISS	ISS	ISS
Temperature Control	Sensible HX	Condensing HX	Condensing HX	Condensing HX	Condensing HX
O2 Supply	HP Gas	HP Gas	Electrolysis (vent H2)	Electrolysis	Electrolysis
N2 Supply	HP Gas	HP Gas	HP Gas	HP Gas	HP Gas
Water					
Humidity Cond. Recovery	None	VPCAR w/o AES **	VPCAR w/o AES **	VPCAR w/o AES **	VPCAR w/o AES **
Urine Water Recovery	None	VPCAR w/o AES **	VPCAR w/o AES **	VPCAR w/o AES **	VPCAR w/o AES **
Hygiene Water Recovery	None	VPCAR w/o AES **	VPCAR w/o AES **	VPCAR w/o AES **	VPCAR w/o AES **
Laundry Water Recovery*	None	VPCAR w/o AES **	VPCAR w/o AES **	VPCAR w/o AES **	VPCAR w/o AES **
Waste					
Fecal Collection	Simplified EDO	Simplified EDO	Simplified EDO	Simplified EDO	Simplified EDO
Urine Collection	Simplified EDO	Simplified EDO	Simplified EDO	Simplified EDO	Simplified EDO
Water Recovery from Waste	None	None	PMWC + Lyoph	PMWC + Lyoph	PMWC + Lyoph

* If laundry option is selected

** 93% Recovery Specified

Water Assumptions

Category	Value	Units	Notes
Drinking Water	1.10	kg/CM/day	Specified to make sum = 2.5
Food Rehydration Water	1.40	kg/CM/day	ALSSAT default for STM + Bulk
Drinking + Food Rehydration Water	2.50	kg/CM/day	Total spec by M. Anderson
Urinal Flush Water	-	kg/CM/day	Considered part of hygiene water
Oral Hygiene Water	-	kg/CM/day	Considered part of hygiene water
Hand/Face Wash Water	1.50	kg/CM/day	ALSSAT default
Shower Water	3.45	kg/CM/day	ALSSAT default
Laundry Water	7.30	kg/CM/day	Spec by M. Anderson, for cases with laundry
EVA Drinking Water	1.90	kg/CM/EVA	ALSSAT default*
EVA Cooling Water	1.20	kg/CM/EVA	Per B. Conger for Lunar Pole Cold Case
EVA Cooling Loop Flush	0.25	kg/CM/EVA	Per B. Conger, also ALSSAT default
Total EVA Water	3.35	kg/CM/EVA	

* ALSSAT default of 1.9 kg/CM/EVA is equivalent to HSIR requirement of 240 ml/hr additional drinking water for EVA.

Other Key Assumptions

- Habitability
  - Shuttle training menu with bulk food storage and no salad
  - Atmosphere is 55 kPa (8 psia), 34% O_2, with N_2 diluent
- EVA
  - Six 8-hour sorties per week
  - 2 crew members per sortie
  - Oxygen consumption of 0.72 kg/CM/EVA
  - Spacesuit Water Membrane Evaporator (SWME) cooling (except where water loss set to zero)

ESM Factors

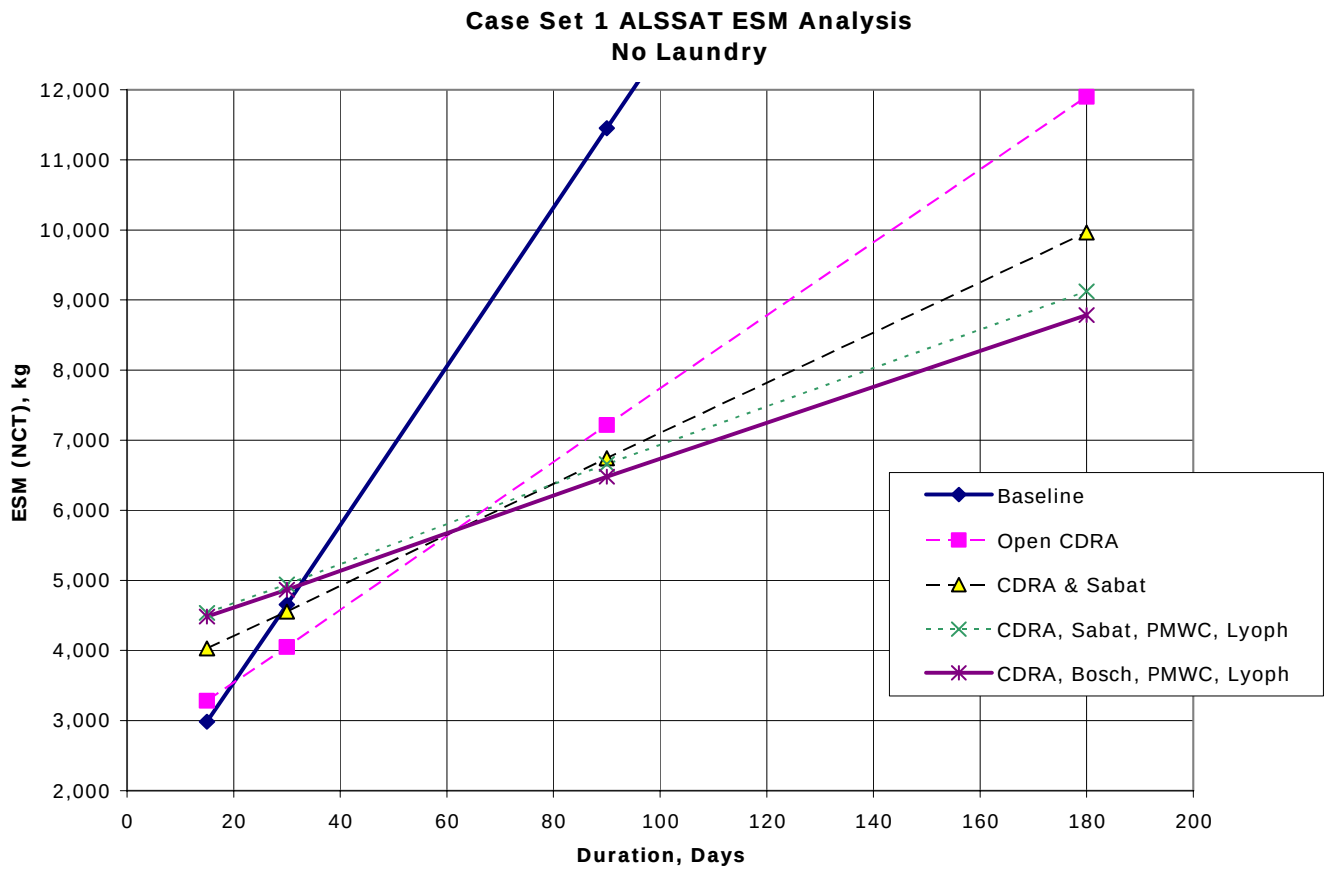
- The Lunar Outpost factors from the Lunar Reference Mission Report[1] were used

ESM Factor	Value	Key Assumptions
Volume Factor	100 kg/m^3	Architecture similar to ISS modules, but with enhanced radiation protection consisting of the equivalent of 50 kg/m^2 of polyethylene integrated into the vehicle primary structure.
Power Factor	274.1 kg/kW	South Polar site on the North Rim of Shackleton Crater. Solar power generation with regenerable fuel cells and cryogenic reactants for energy storage.
Thermal Factor	31.6 kg/kW	South Polar site on the North Rim of Shackleton Crater with horizontal radiators using 10-mil silver Teflon, 3.5 kg/m^3. Active Thermal Control System is two loops with single fluid 60/40 propylene glycol/H_2O. 90% of thermal load is acquired via coldplate, 10% with condensing heat exchanger

[1]Hanford, A. J., "A Lunar Reference Mission for Advanced Life Support," ESCG-4470-06-TEAN-DOC-0041, Engineering and Science Contract Group, Houston, Texas, 05 April 2006.

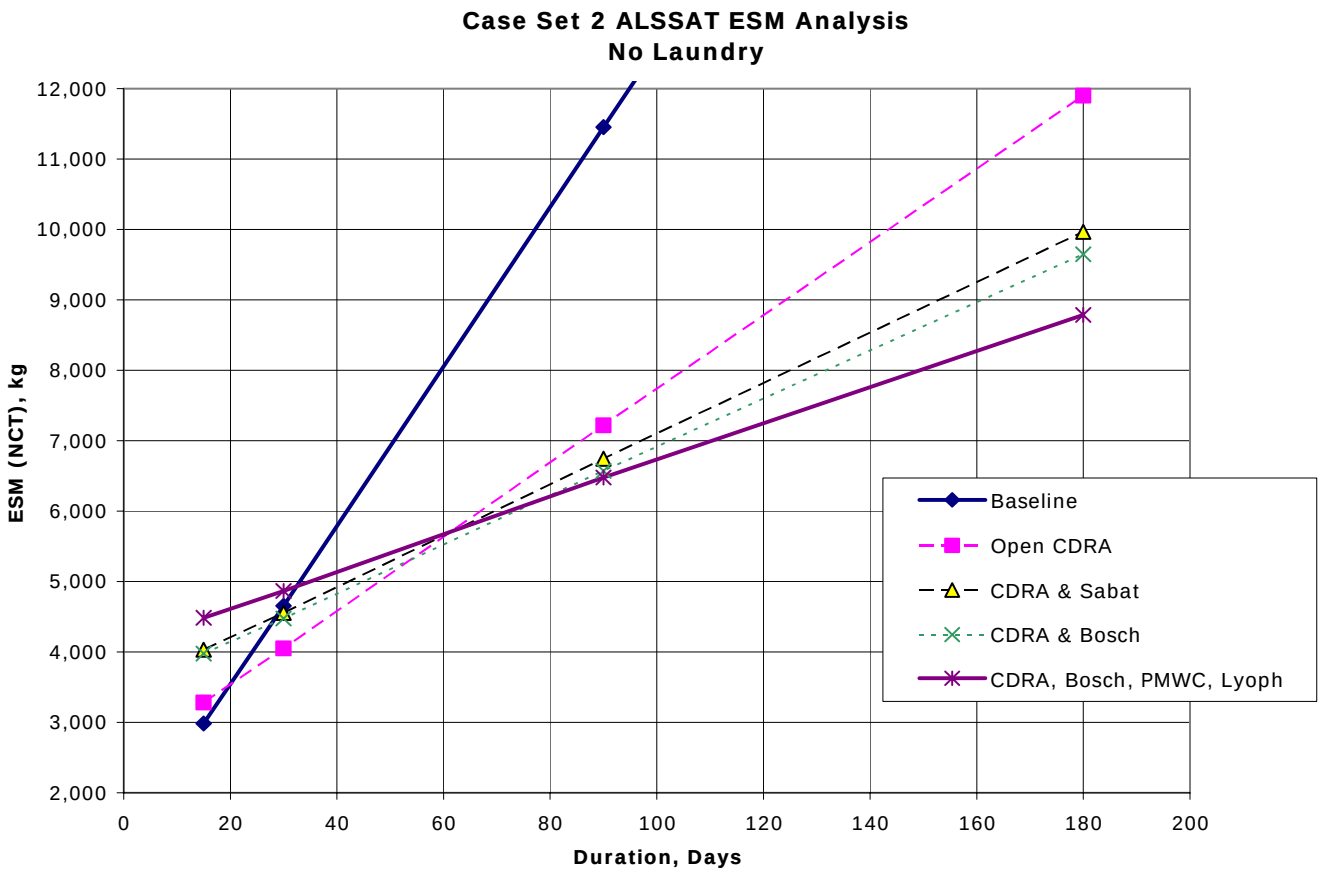
Case Set 1 Analysis with Disposable Clothing

From	To	Preferred Technology
1 day	20 days	Open Air & Water
20 days	61 days	Open CDRA
61 days	On up	CDRA, Bosch, PMWC, Lyophilization



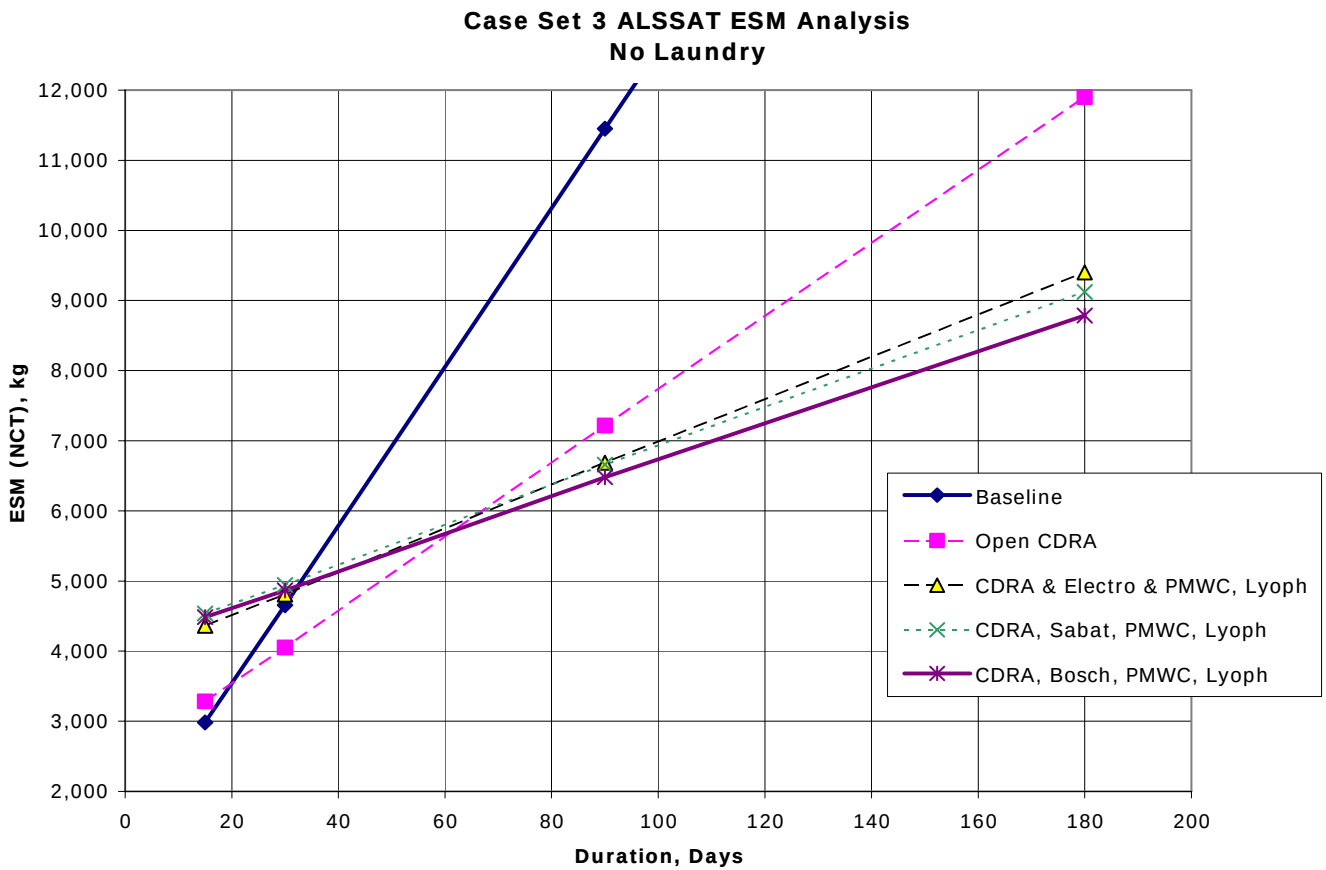
Case Set 2 Analysis with Disposable Clothing

From	To	Preferred Technology
1 day	20 days	Open Air & Water
20 days	54 days	Open CDRA
54 days	77 days	CDRA & Bosch
77 days	On up	CDRA, Bosch, PMWC, Lyophilization



Case Set 3 Analysis with Disposable Clothing

From	To	Preferred Technology
1 day	20 days	Open Air & Water
20 days	61 days	Open CDRA
61 days	On up	CDRA, Bosch, PMWC, Lyophilization

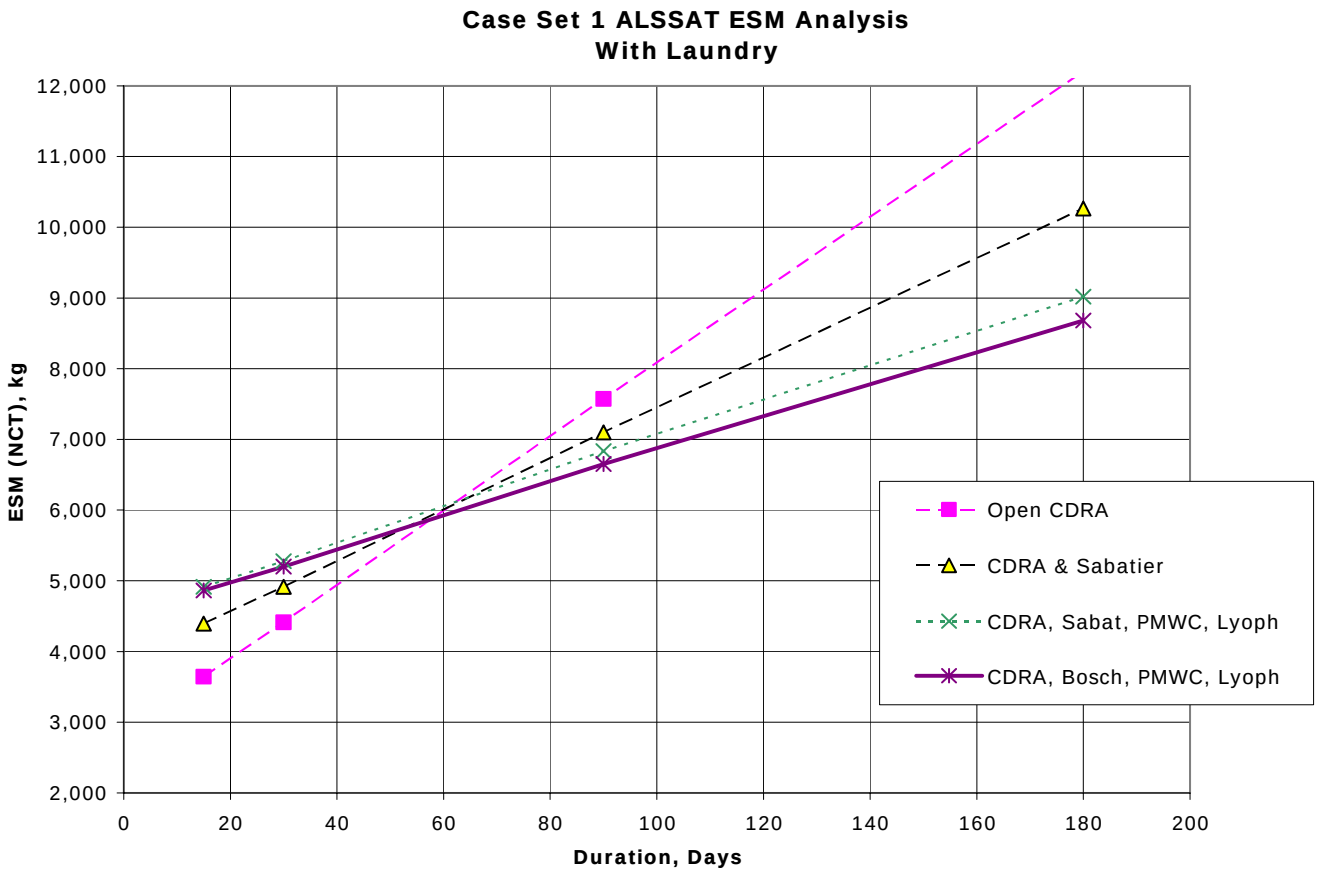


Case Sets with Laundry

- ALSSAT clothing/laundry defaults were used
- For disposable clothing, the mass is 0.486 kg/CM/day, and the volume is 0.00285 m^3/CM/day
- Clothing mass ranges from 0.07 kg/CM/day for missions up to 120 days down to 0.02 kg/CM/day for missions over 400 days
- Clothing volume ranges from 0.00041 m^3/CM/day for missions up to 120 days down to 0.00012 m^3/CM/day for missions over 400 days

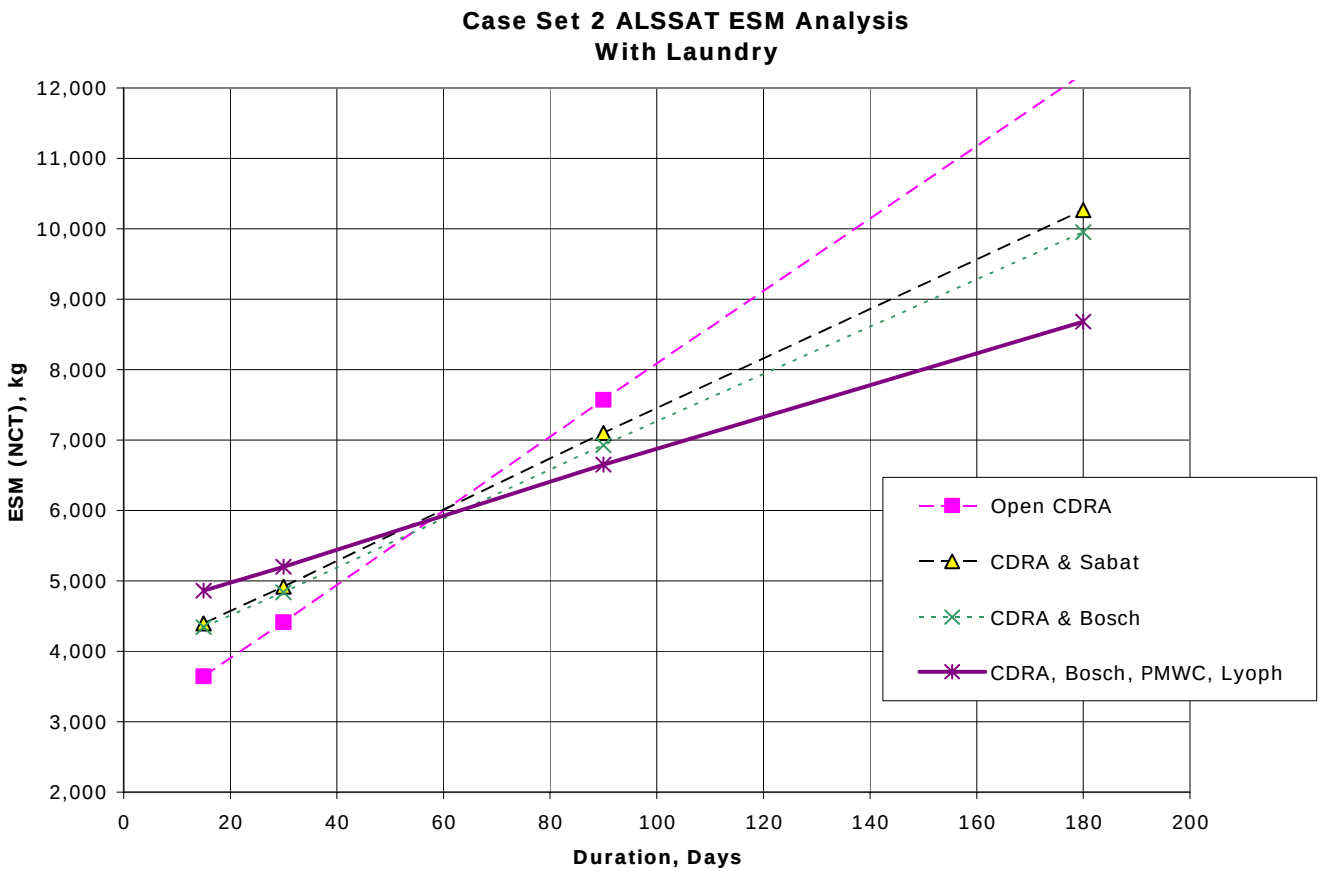
Case Set 1 Analysis with Laundry

From	To	Preferred Technology
1 day	58 days	Open CDRA
58 days	On up	CDRA, Bosch, PMWC, Lyophilization



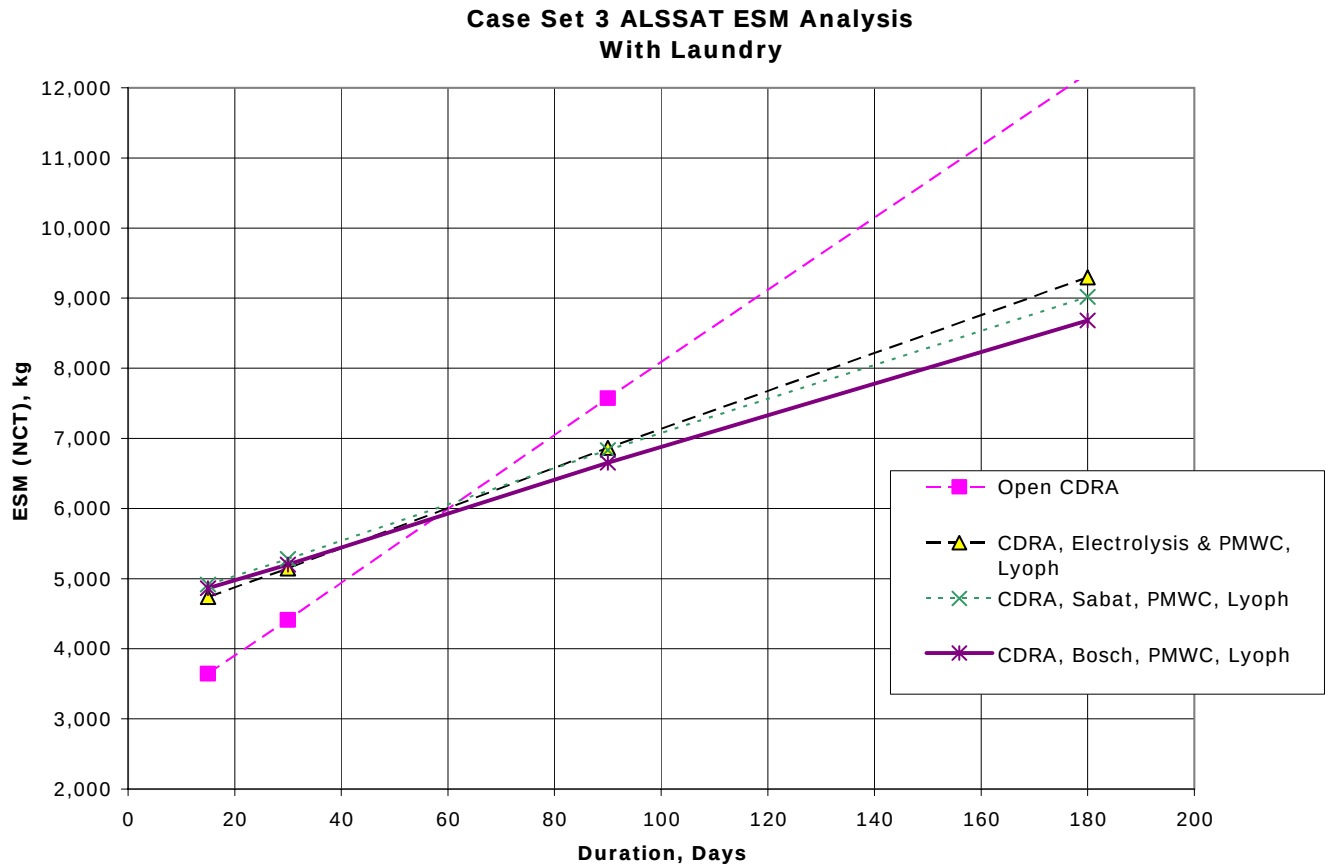
Case Set 2 Analysis with Laundry

From	To	Preferred Technology
1 day	54 days	Open CDRA
54 days	64 days	CDRA & Bosch
64 days	On up	CDRA, Bosch, PMWC, Lyophilization



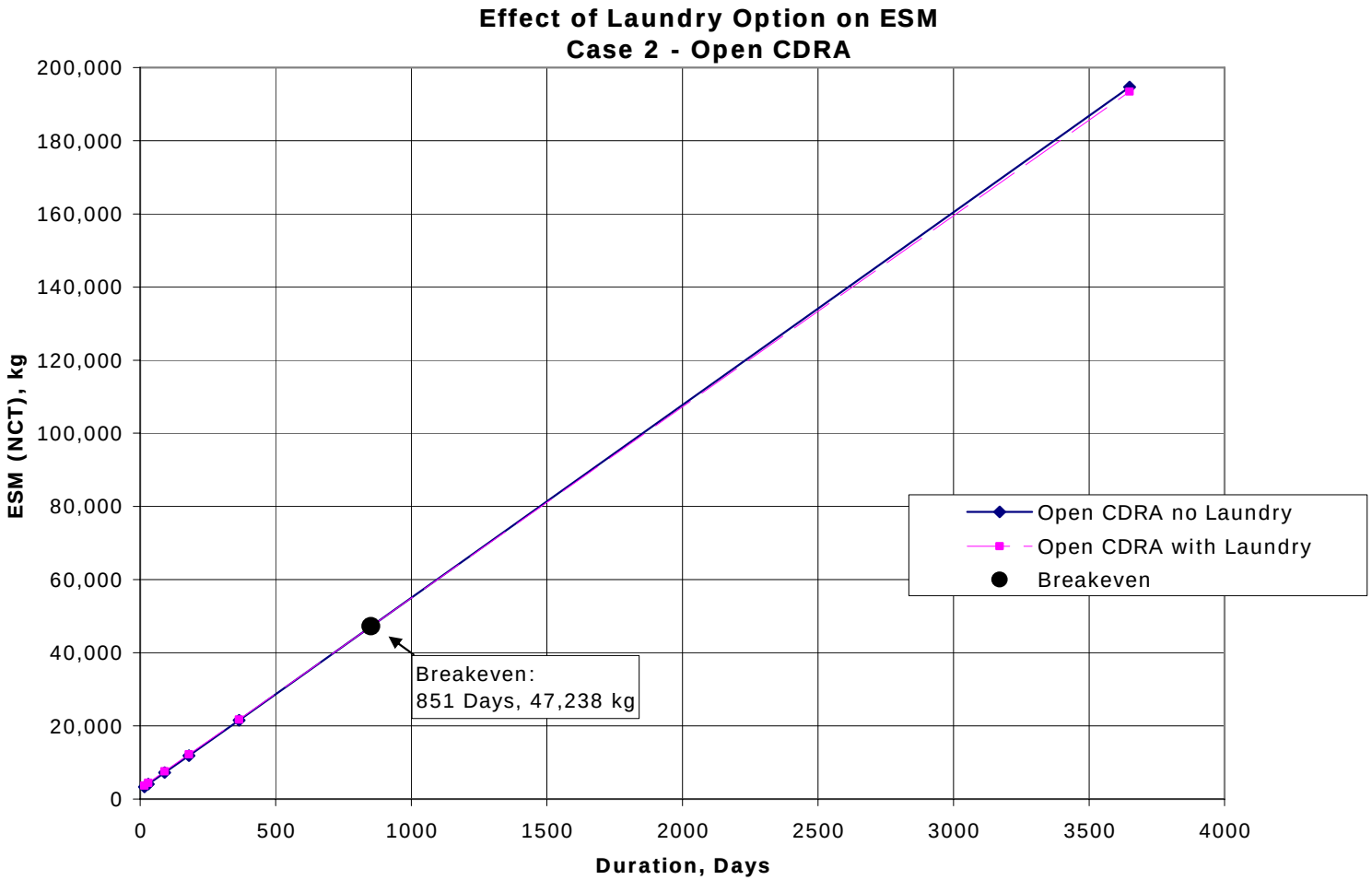
Case Set 3 Analysis with Laundry

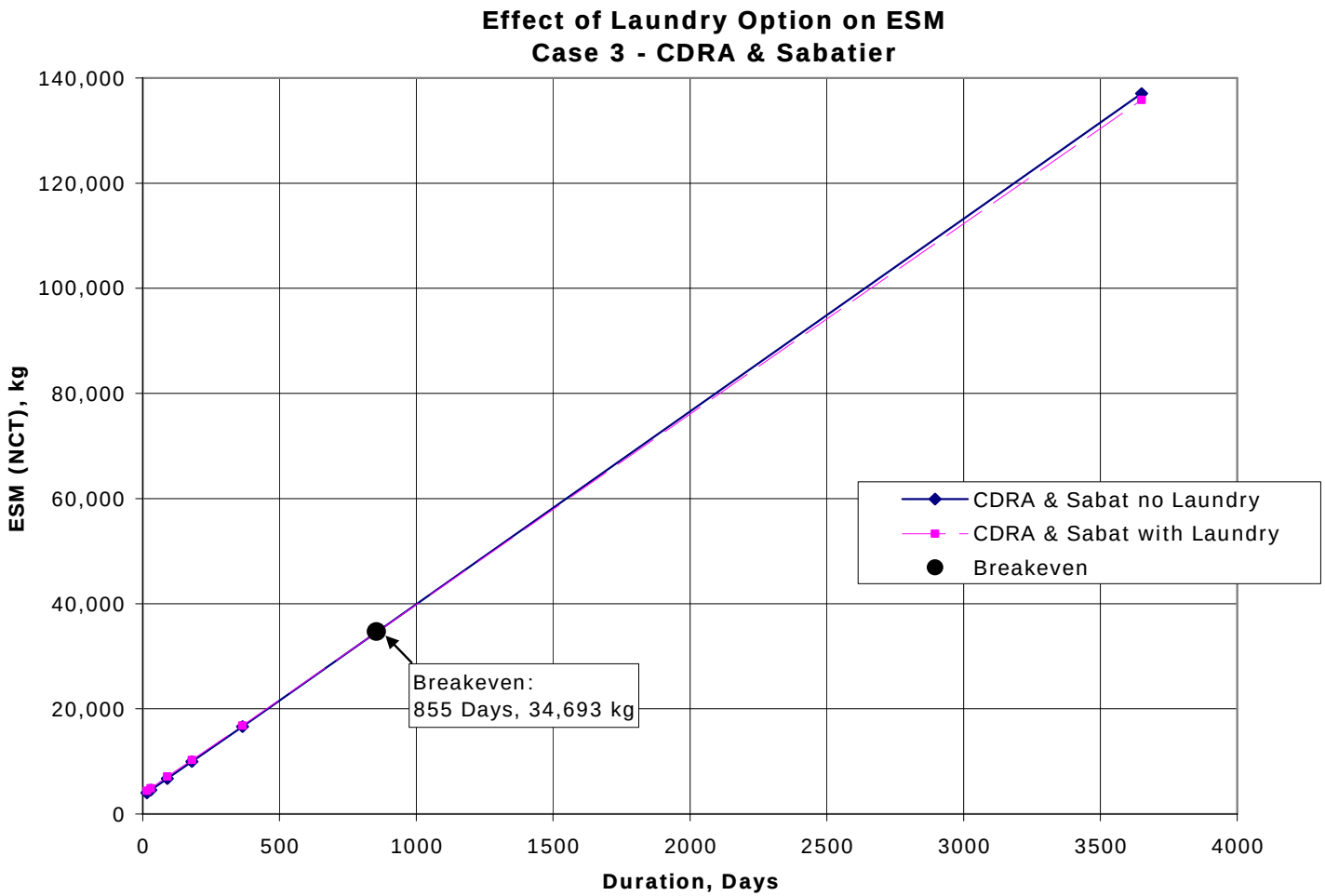
From	To	Preferred Technology
1 day	58 days	Open CDRA
58 days	On up	CDRA, Bosch, PMWC, Lyophilization

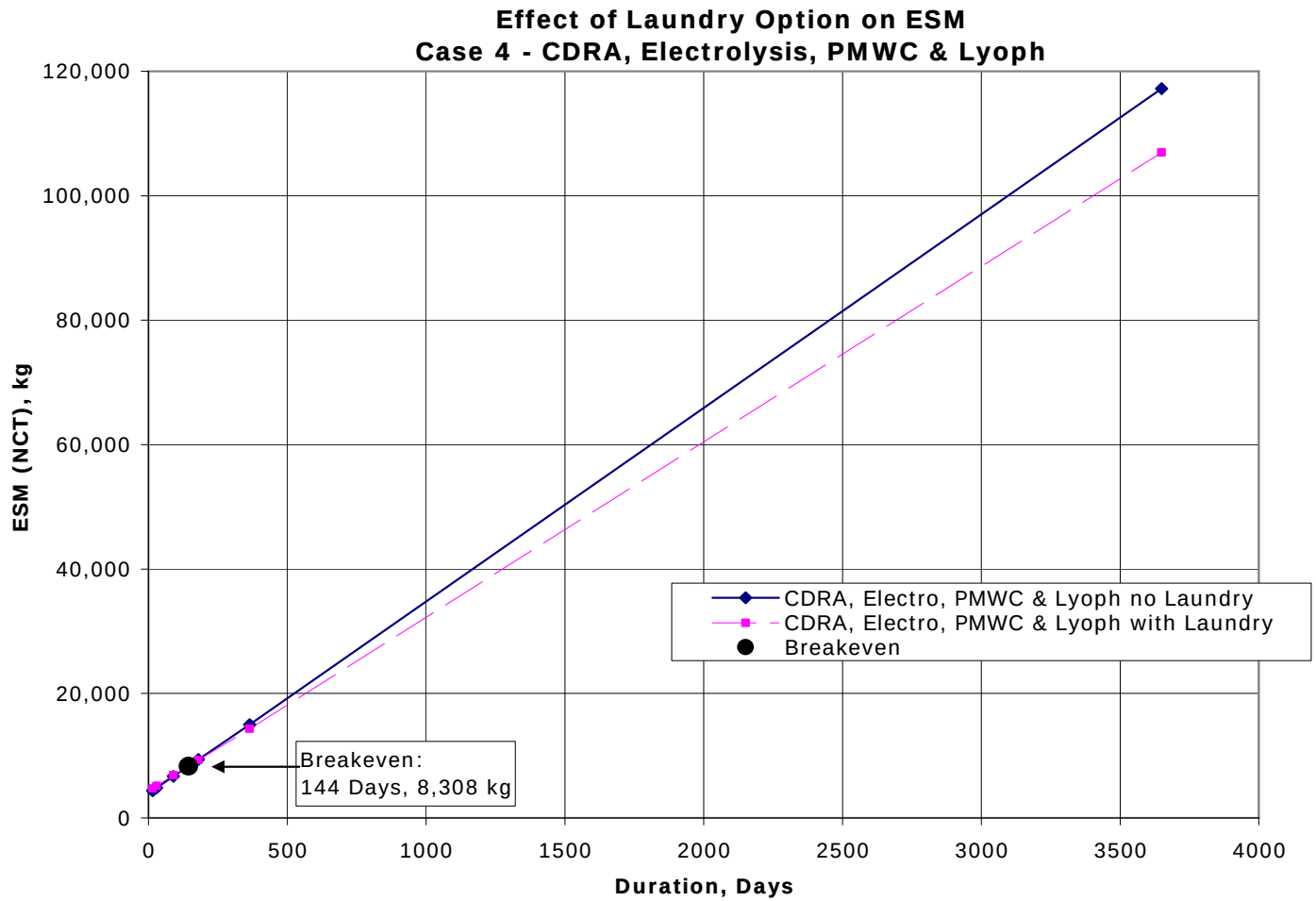


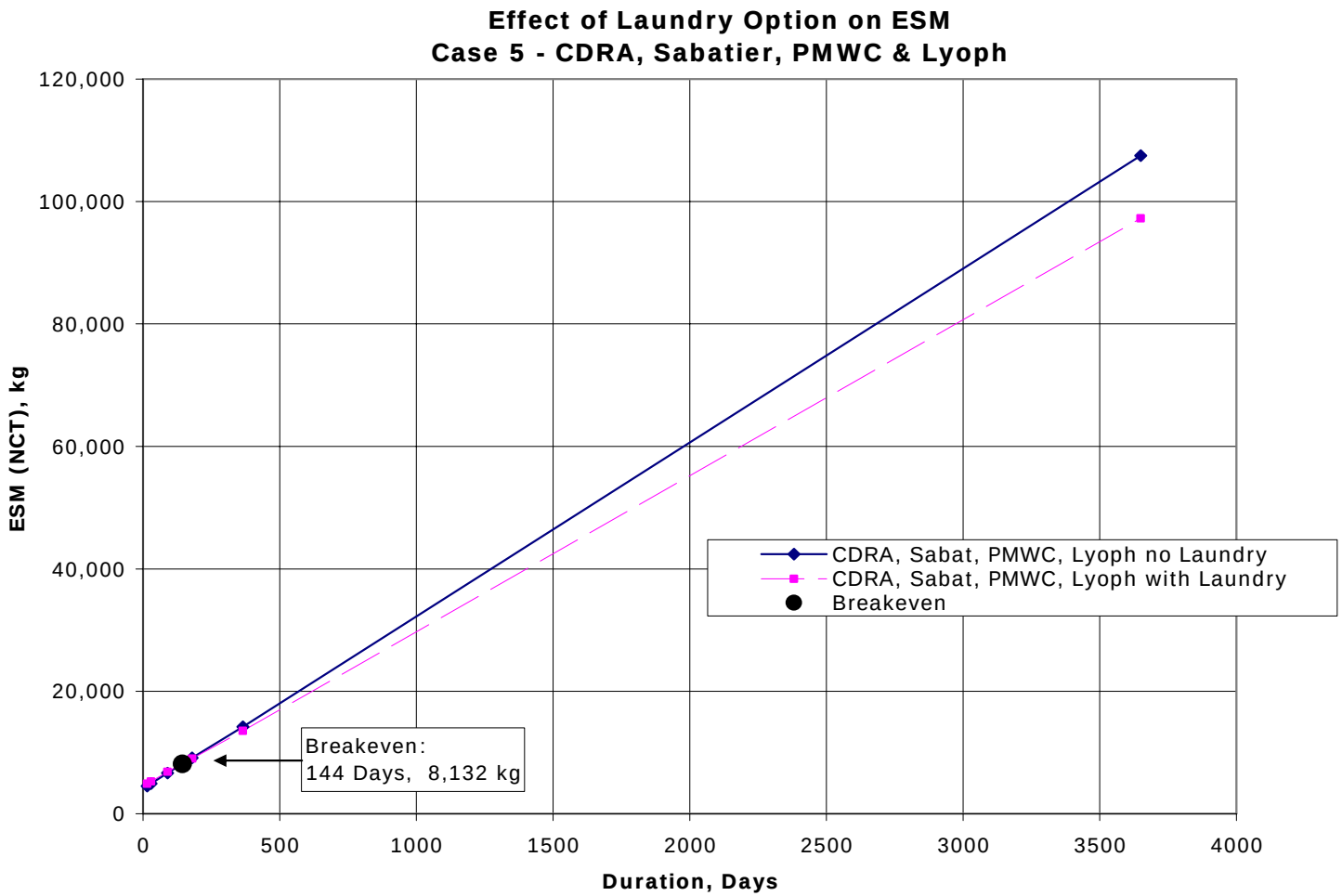
Effect of Laundry on Individual Technology Combinations

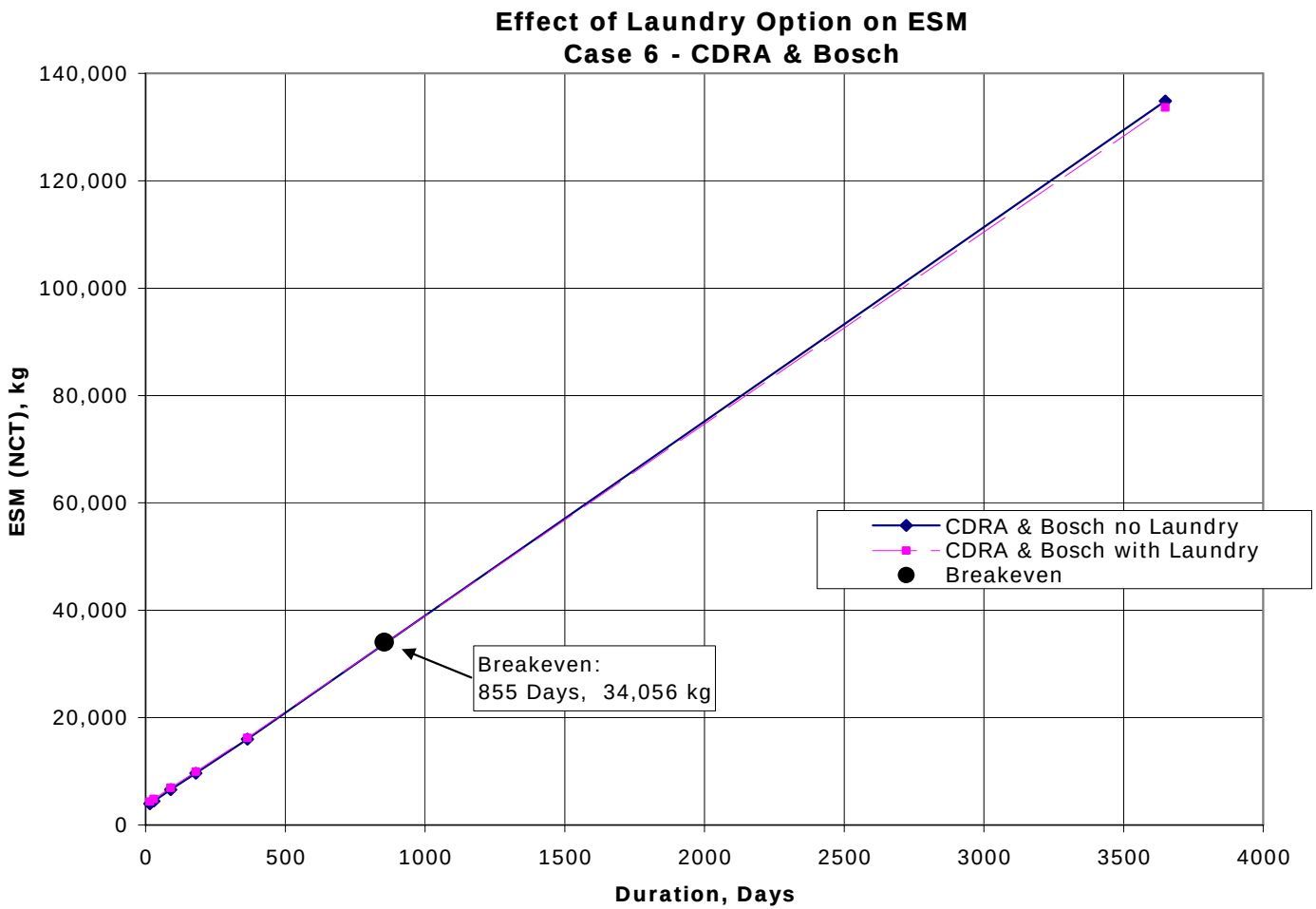
- Crossover point depends most strongly on whether water is recovered from waste
  - Water recovery from wastewater is set at 93%. The 7% brine residual is sent to the waste processing system
- With no water recovery from waste (Cases 2, 3, and 6), laundry becomes favorable at ~850 days, with ESM savings of ~1,200 kg at 3,650 days
- With water recovery from waste, (Cases 4, 5 and 7) laundry becomes favorable at ~144 days, with ESM savings of ~10,300 kg at 3,650 days

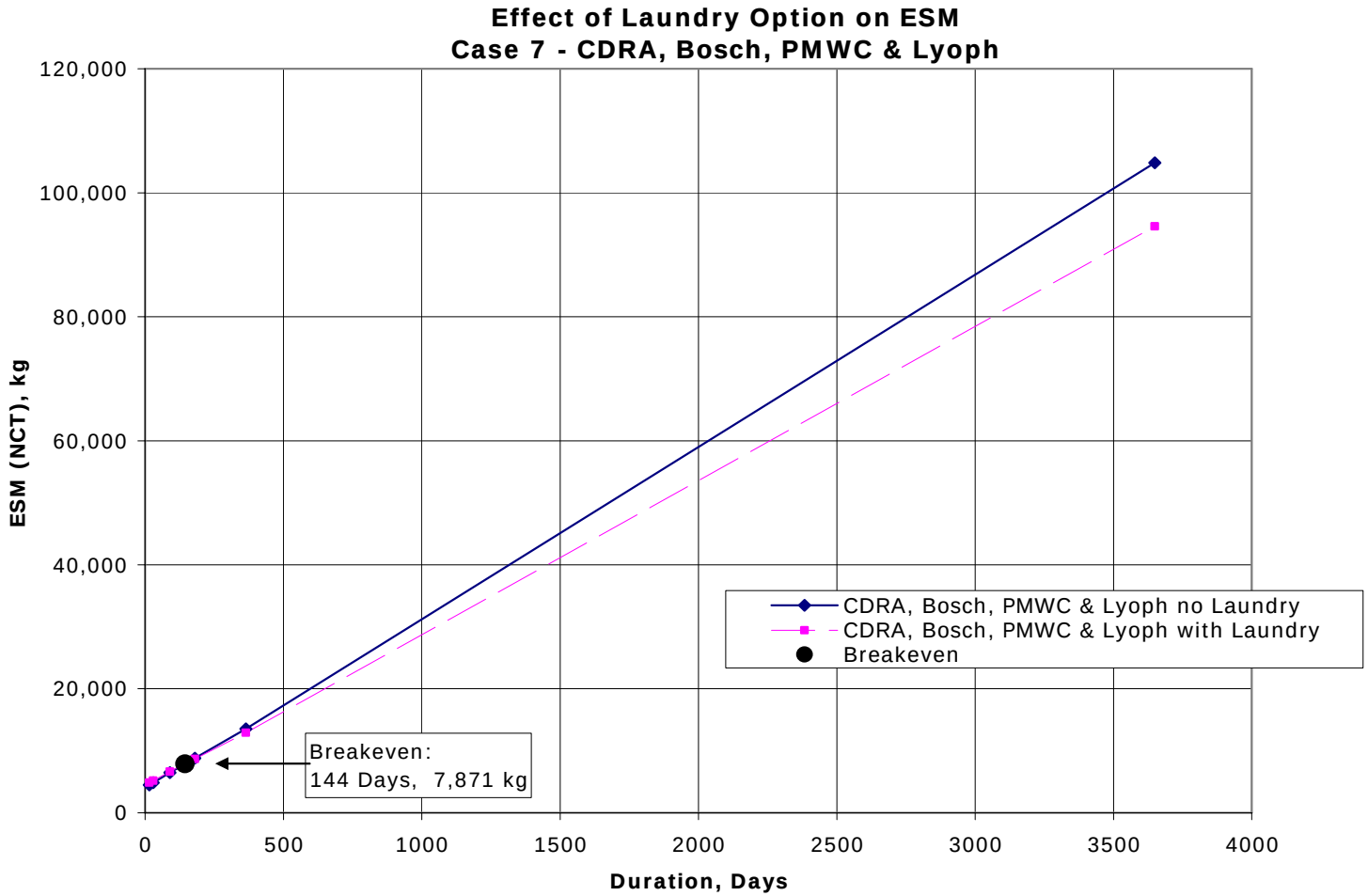

Effect of Laundry Option on ESM
Case 2 - Open CDRA
ESM (NCT), kg
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
0
500
1000
1500
2000
2500
3000
3500
4000
Duration, Days
Open CDRA no Laundry
Open CDRA with Laundry
Breakeven
Breakeven:
851 Days, 47,238 kg


Effect of Laundry Option on ESM
Case 3 - CDRA & Sabatier
ESM (NCT), kg
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
0
500
1000
1500
2000
2500
3000
3500
4000
Duration, Days
CDRA & Sabat no Laundry
CDRA & Sabat with Laundry
Breakeven
Breakeven:
855 Days, 34,693 kg


Effect of Laundry Option on ESM
Case 4 - CDRA, Electrolysis, PMWC & Lyoph
ESM (NCT), kg
120,000
100,000
80,000
60,000
40,000
20,000
0
0
500
1000
1500
2000
2500
3000
3500
4000
Duration, Days
CDRA, Electro, PMWC & Lyoph no Laundry
CDRA, Electro, PMWC & Lyoph with Laundry
Breakeven
Breakeven:
144 Days, 8,308 kg


Effect of Laundry Option on ESM
Case 5 - CDRA, Sabatier, PMWC & Lyoph
ESM (NCT), kg
120,000
100,000
80,000
60,000
40,000
20,000
0
0
500
1000
1500
2000
2500
3000
3500
4000
Duration, Days
CDRA, Sabat, PMWC, Lyoph no Laundry
CDRA, Sabat, PMWC, Lyoph with Laundry
Breakeven
Breakeven:
144 Days, 8,132 kg


Effect of Laundry Option on ESM
Case 6 - CDRA & Bosch
ESM (NCT), kg
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
0
500
1000
1500
2000
2500
3000
3500
4000
Duration, Days
CDRA & Bosch no Laundry
CDRA & Bosch with Laundry
Breakeven
Breakeven:
855 Days, 34,056 kg


Effect of Laundry Option on ESM
Case 7 - CDRA, Bosch, PMWC & Lyoph
ESM (NCT), kg
120,000
100,000
80,000
60,000
40,000
20,000
0
0
500
1000
1500
2000
2500
3000
3500
4000
Duration, Days
CDRA, Bosch, PMWC & Lyoph no Laundry
CDRA, Bosch, PMWC & Lyoph with Laundry
Breakeven
Breakeven:
144 Days, 7,871 kg

Effect of EVA Cooling Water on ESM

- All cases described above used 1.2 kg/CM/EVA cooling water loss
- Case set 2 with laundry was re-evaluated with cooling water loss set to zero
- ESM impacts at 3,650 days:
  - EVA cooling water mass is 7,510 kg
  - 10,712 kg ESM delta without water recovery from waste
  - 6,864 kg ESM delta with water recovery from waste

Conclusions

- With disposable clothing or laundry, the most regenerative option (CDRA, Bosch, PMWC and Lyophilization) had the lowest ESM after 77 days or less for all case sets with both laundry options
- When comparing each technology individually with the two clothing options:
  - Laundry has the lower ESM after about 850 days if no water recovery from waste
  - Laundry has the lower ESM after about 144 days with water recovery from waste
- 3,650 days ESM savings when EVA cooling water was set to zero:
  - 10,712 kg without water recovery from waste
  - 6,864 kg with water recovery from waste (cooling water mass savings calculated at 7,510 kg)

Conclusions (continued)

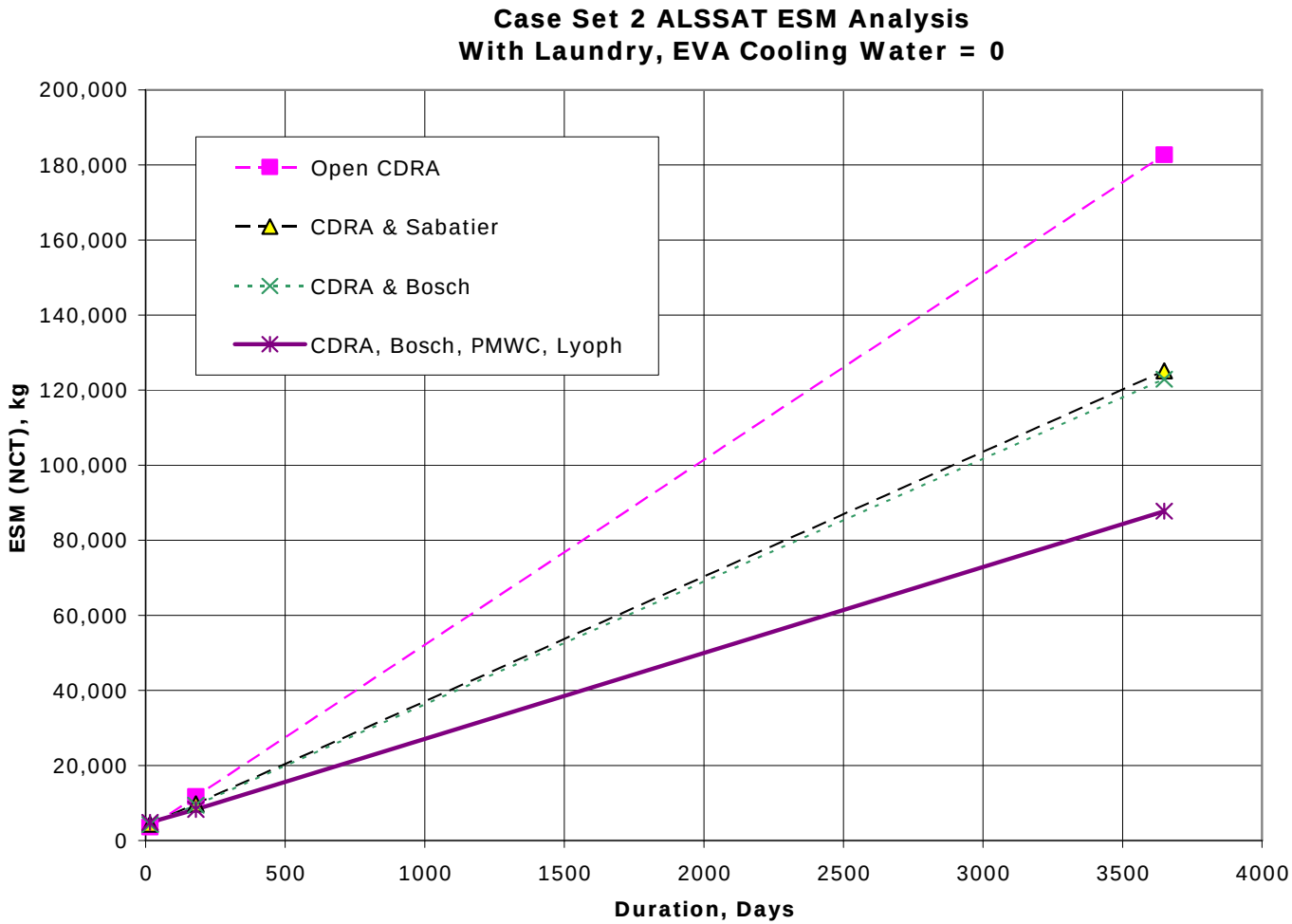
- Case Set 2 results indicate that water recovery from waste pays off at around 77 days for disposable clothing, and 64 days with laundry
- The results imply that Sabatier alone is never favorable over Bosch. However, it is acknowledged that the current Bosch data in ALSSAT will give low ESMs, so this conclusion is questionable

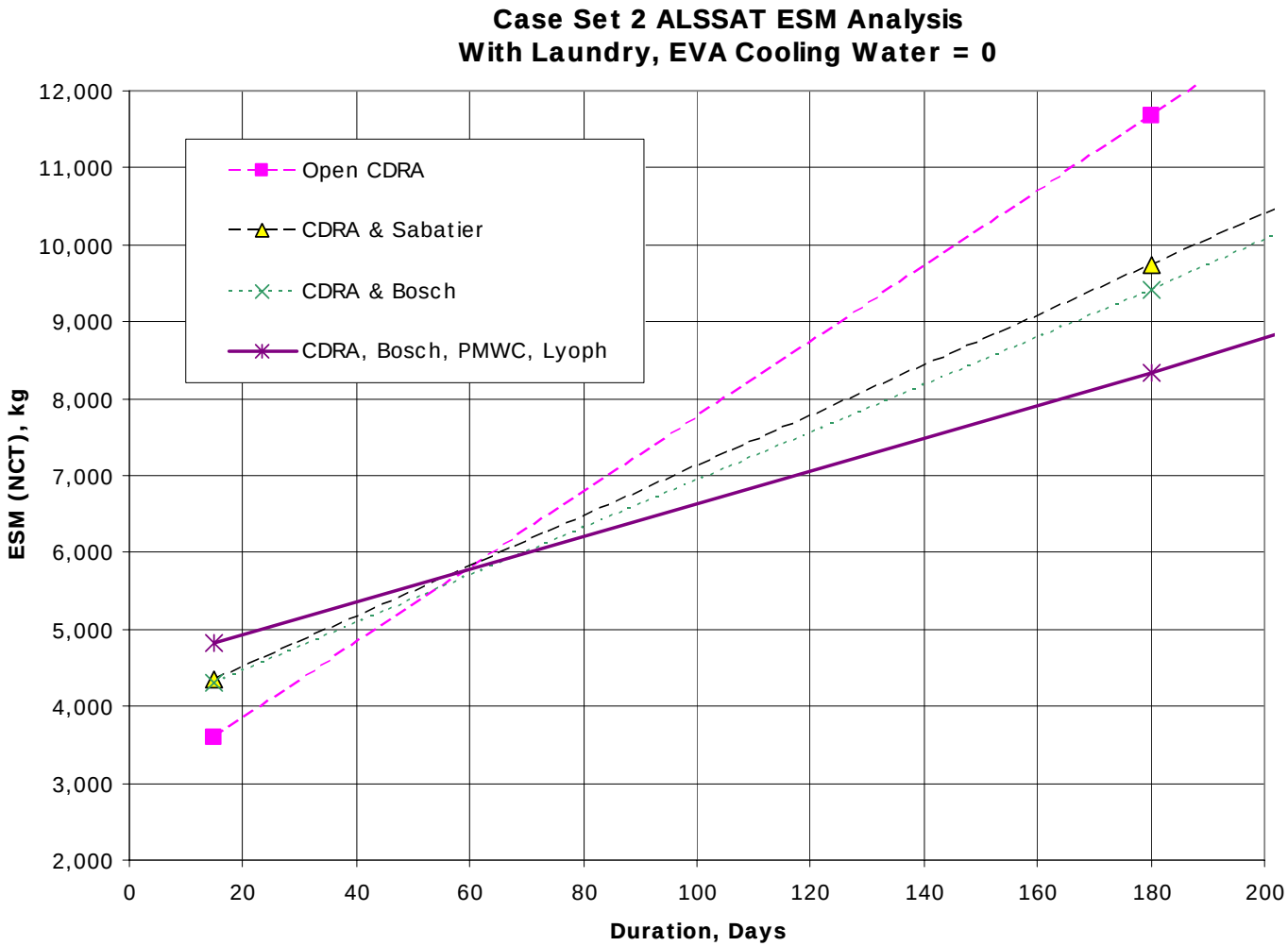
Acronyms

AES	Air Evaporation System
ALSSAT	Advanced Life Support Sizing and Analysis Tool
ATCO	Ambient Temperature Catalytic Oxidation
CAMRAS	Carbon Dioxide and Moisture Removal Amine System
CDRA	Carbon Dioxide Removal Assembly
CDS	Cascade Distillation System
CEV	Crew Exploration Vehicle
CFR	Carbon Formation Reactor
CH_4	Methane
CHX	Condensing Heat Exchanger
CM	Crew Member
CO_2	Carbon Dioxide
EDO	Extended Duration Orbiter
ELS	Exploration Life Support
ESCG	Engineering and Science Contract Group
ESM	Equivalent System Mass
EVA	Extravehicular Activity
GAC	Granular Activated Carbon
H_2	Hydrogen
H_2O	Water
HX	Heat Exchanger
ISS	International Space Station
LiOH	Lithium Hydroxide
N_2	Nitrogen
NASA	National Aeronautics and Space Administration
NCT	No Crew Time
O_2	Oxygen
PMWC	Plastic Melt Waste Compactor
PMWCL	Plastic Melt Waste Compactor with Lyophilization
SIMA	Systems Integration, Modeling and Analysis
VPCAR	Vapor-Phase Catalytic Ammonia Removal

Backup Slides

Effect of EVA Cooling Water on Case Set 2 with Laundry Option ESM Values			
All ESM Values and Deltas are in kg			
	Case 2L	Case 2L	
	Open CDRA with Laundry	Open CDRA with Laundry	
Duration, Days	EVA CW = 1.2 kg/CM/EVA	EVA CW = 0	Delta
15	3,645	3,604	-41
180	12,202	11,675	-527
3650	193,422	182,711	-10,711
	Case 3L	Case 3L	
	CDRA & Sabat with Laundry	CDRA & Sabat with Laundry	
Duration, Days	EVA CW = 1.2 kg/CM/EVA	EVA CW = 0	Delta
15	4,395	4,354	-41
180	10,268	9,741	-527
3650	135,818	125,104	-10,713
	Case 6L	Case 6L	
	CDRA & Bosch with Laundry	CDRA & Bosch with Laundry	
Duration, Days	EVA CW = 1.2 kg/CM/EVA	EVA CW = 0	Delta
15	4,341	4,300	-41
180	9,951	9,423	-527
3650	133,643	122,930	-10,713
	Case 7L	Case 7L	
	CDRA, Bosch, PMWC & Lyoph with Laundry	CDRA, Bosch, PMWC & Lyoph with Laundry	
Duration, Days	EVA CW = 1.2 kg/CM/EVA	EVA CW = 0	Delta
15	4,862	4,820	-42
180	8,682	8,326	-356
3650	94,582	87,718	-6,864


Case Set 2 ALSSAT ESM Analysis
With Laundry, EVA Cooling Water = 0
ESM (NCT), kg
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
0
500
1000
1500
2000
2500
3000
3500
4000
Duration, Days
Open CDRA
CDRA & Sabatier
CDRA & Bosch
CDRA, Bosch, PMWC, Lyoph


Case Set 2 ALSSAT ESM Analysis
With Laundry, EVA Cooling Water = 0
ESM (NCT), kg
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
0
20
40
60
80
100
120
140
160
180
200
Duration, Days
Open CDRA
CDRA & Sabatier
CDRA & Bosch
CDRA, Bosch, PMWC, Lyoph