BREATH computer modelling of submarine atmosphere purge regimes

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Introduction

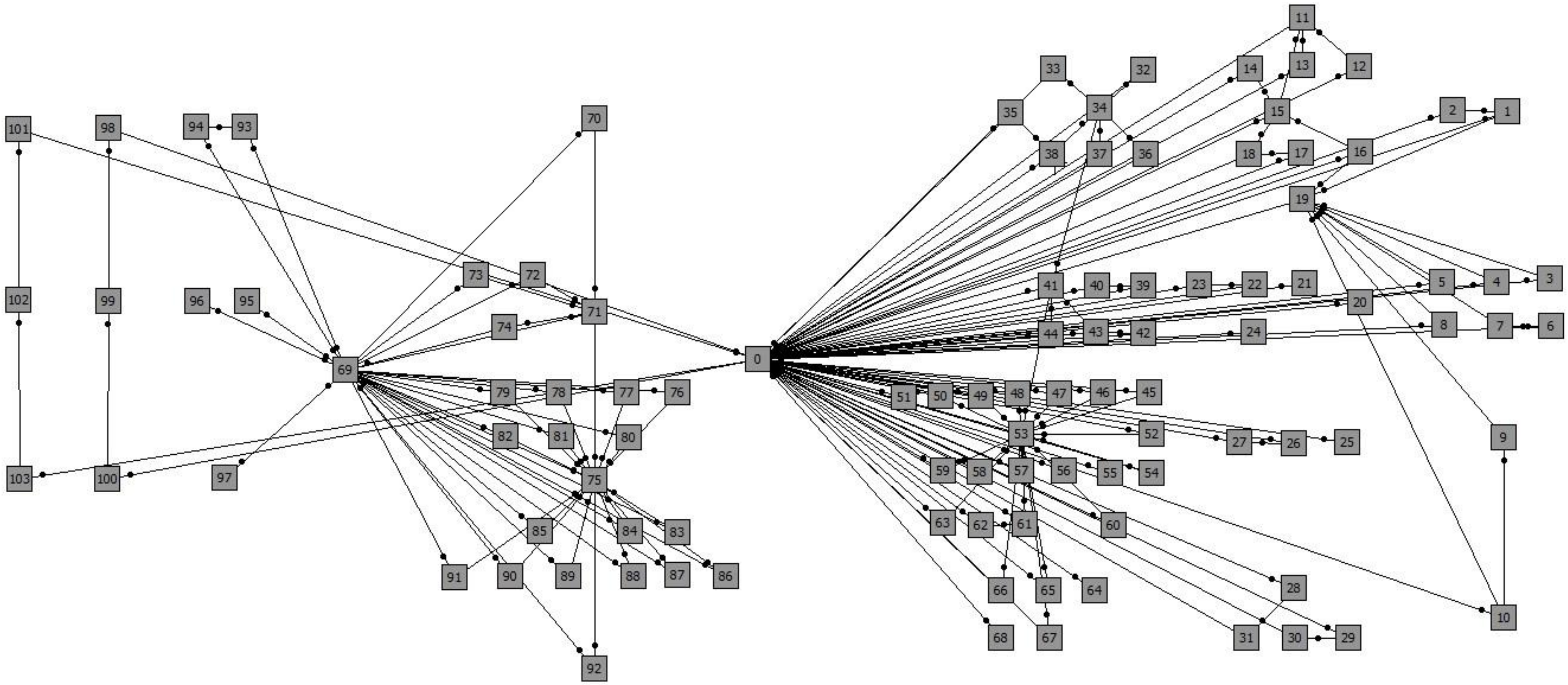
- Snorkel first trialled on Dutch submarines late 1930's
- The running of diesel generators on submerged submarines has always been a potentially hazardous operation
- Exhaust gases contain toxic levels of carbon monoxide (CO)
- Potential exposure routes:
  - Leaks from exhaust
  - Re-ingestion of exhaust plume through Snort Induction Mast
- Operation of the Snort Induction Mast (SIM) corresponds Royal Navy Vent State Blue
- Computer simulation of potential faults during Vent State Blue

Archive photo of Dutch HMS Sälen (the Seal) snorting.

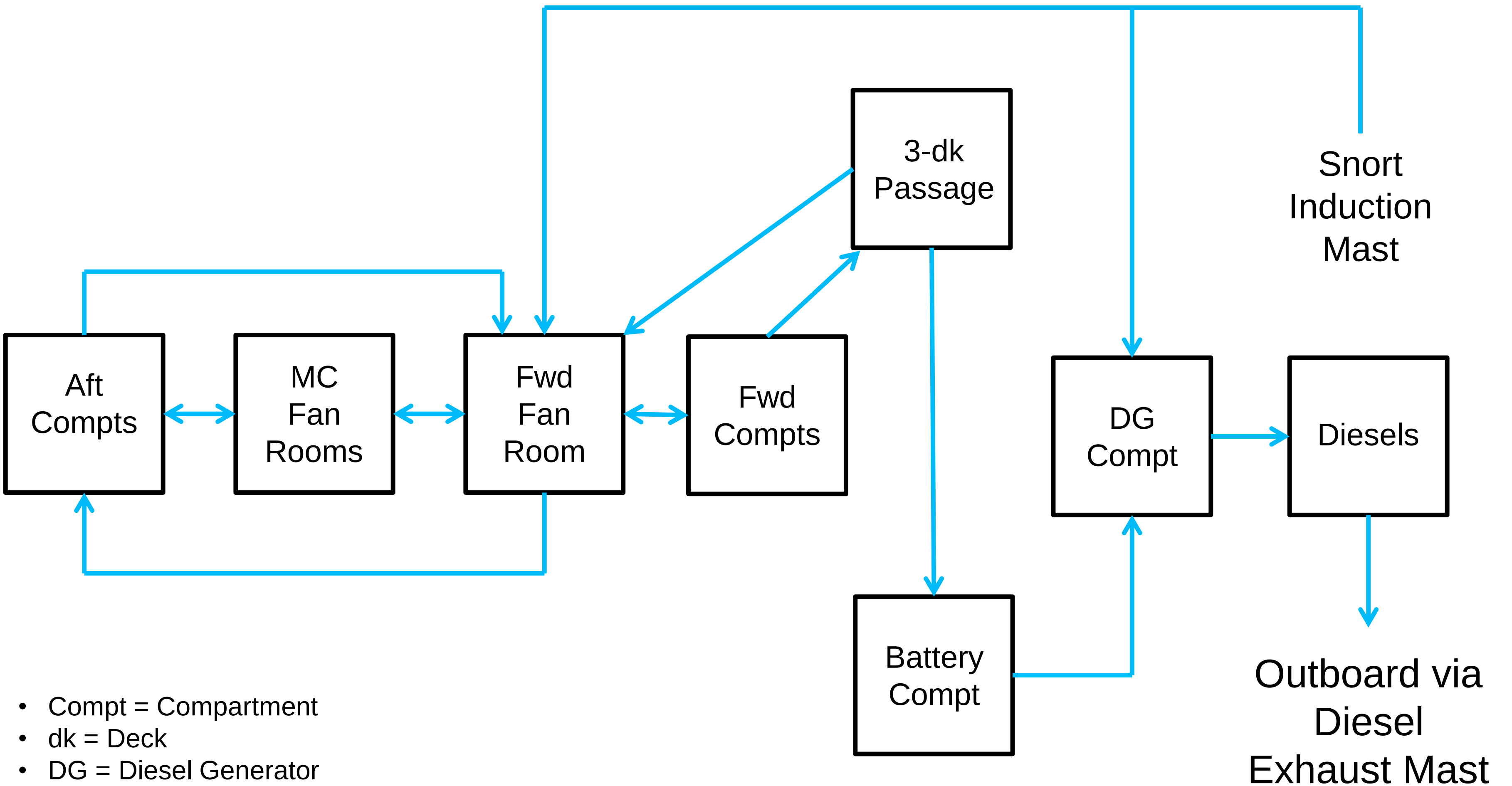
BREATH computer model

- BREATH modelling software was developed jointly by QinetiQ and the Buildings Research Establishment (BRE), but now wholly QinetiQ proprietary
- Underlying mathematical function that drives BREATH is a fourth order Runge-Kutta method
- Validated through practical experiments
  - Small scale using plastic boxes, tubing and carbon dioxide
  - Large scale using building ventilation system and refrigerant gas
- Model uses breathable volumes, ventilation system architecture and ventilation flow rates that are drawn from submarine design specifications
- Inputs include initial contaminant concentrations, production and removal rates

BREATH architecture – From this…



BREATH architecture – To this…



- Compt = Compartment
- dk = Deck
- DG = Diesel Generator
- MC = Missile Compartment

Impact of diesel exhaust leaks – 1

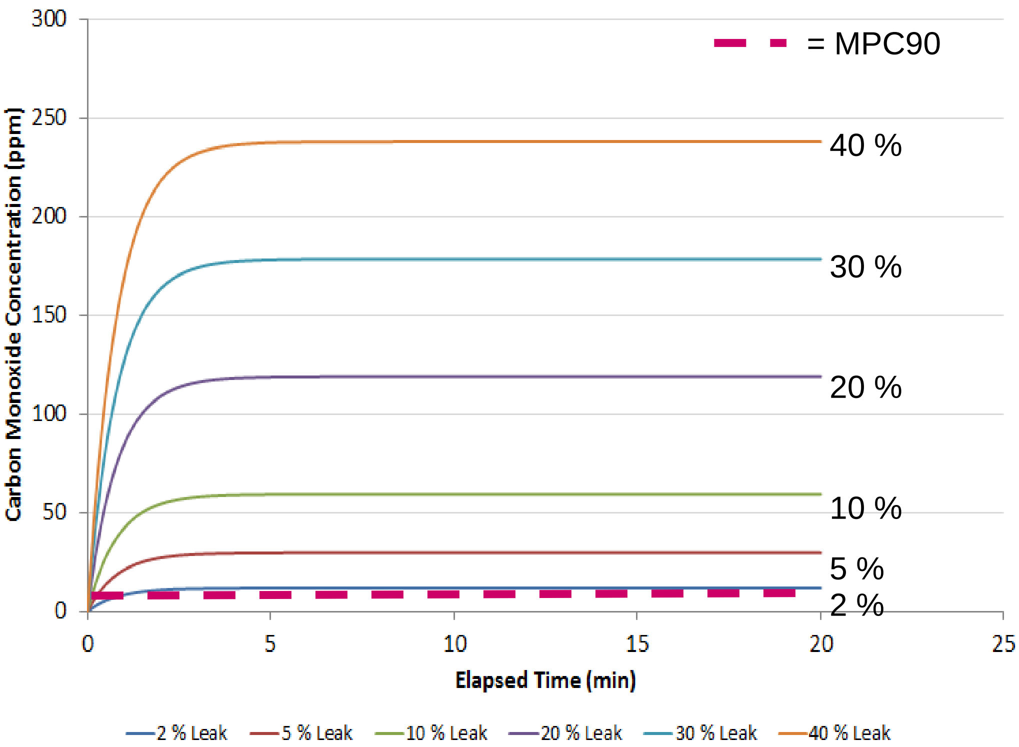
- 200 to 600 ppm CO in diesel exhaust
- Diesel Generators (DG) produce 100 $l.min^{-1}$ of CO
- 6 different exhaust leakage rates modelled, 5 – 40 %
- Leaks greater than 50 % considered unlikely

Exhaust leakage rate (%)	Volumetric exhaust leakage rate ($m^3 \cdot min^{-1}$)	Volumetric Carbon Monoxide Leakage Rate ($l.min^{-1}$)
2	3.4	2
5	8.4	5
10	6.8	10
20	33.6	20
30	50.4	30
40	67.2	40

Diesel exhaust and CO leakage rates

Impact of diesel exhaust leaks – 2

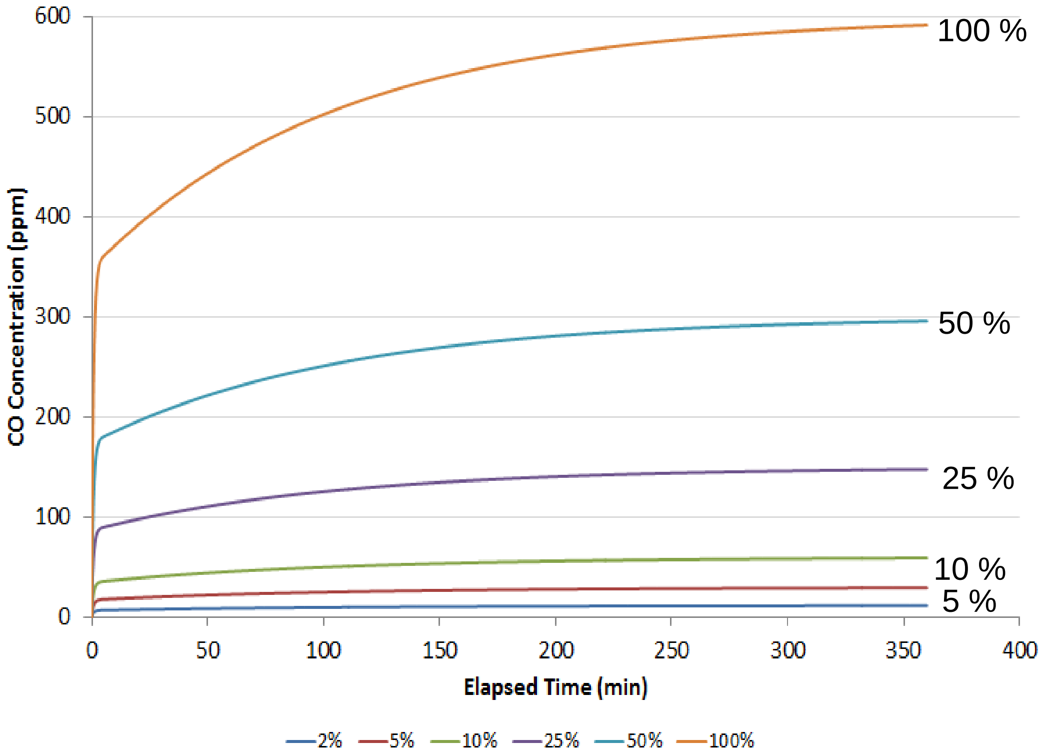
- CO levels rise very quickly in DG compartment
- Even a leak rate of 2 % will breach Royal Navy Maximum Permissible Concentrations (MPC) within 3 min
- Insufficient time for the Central Atmosphere Monitoring System (CAMS) to respond



Modelled effect of Diesel exhaust leakage on DG Compartment CO concentrations

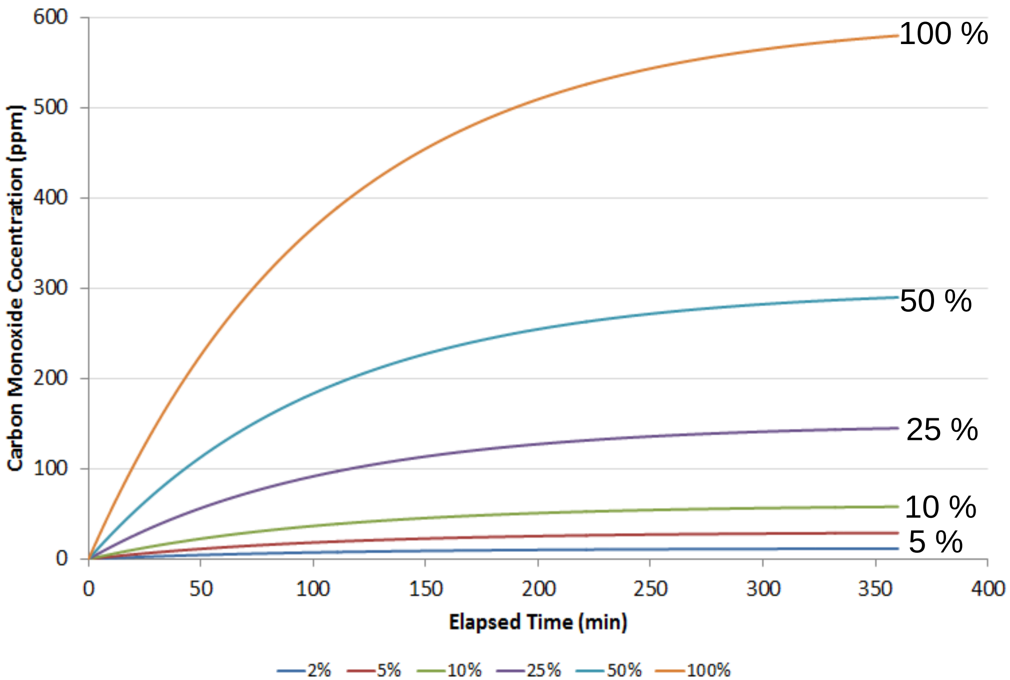
Impact of exhaust re-ingestion – DG Compartment

- BREATH configured so that air entering via the SIM contained CO
- Worst case 100 % re-ingestion gives 600 ppm CO in the inlet
- Rapid rise due to initial re-ingestion
- Slower rise due to build of CO in the rest of the submarine's atmosphere
- Re-ingestion rate of >10 % can breach MPC limits in less than 3 min
- Again, insufficient time for the CAMS to respond



Increase in DG Compartment CO concentration for different degrees of exhaust plume re-ingestion

Impact of exhaust re-ingestion – Whole boat



Re-ingestion (%)	Induced CO conc. (ppm)	Time taken to breach MPC value (min)		
		MPC_{90} (6 ppm)	MPC_{24} (60 ppm)	MPC_{60} (175 ppm)
2	12	-	-	-
5	30	54	-	-
10	60	24	-	-
25	150	9	54	-
50	300	4	24	93
100	600	2	12	37

'Whole boat' times taken to breach CO MPC values

- BREATH simplified rest of submarine as a single "whole boat" compartment
- Slower rises in CO due to larger volume
- Longer times allows CAMS to detect CO increases and raise the alarm

Conclusions and Recommendations

Conclusions

- Both leaks and exhaust re-ingestion can result in CO concentrations in the DG compartment that breach safety levels with minutes
- CAMS cannot respond in sufficient time to provide warning

Recommendations

- Install a rapid response real-time CO monitor into the DG compartment
- Modify ventilation arrangement of Vent State Blue to reduce risk of CO exposure