SecureAI Inc.

Health Condition Assessment of Underground Long-DIstance District Heating Pipelines

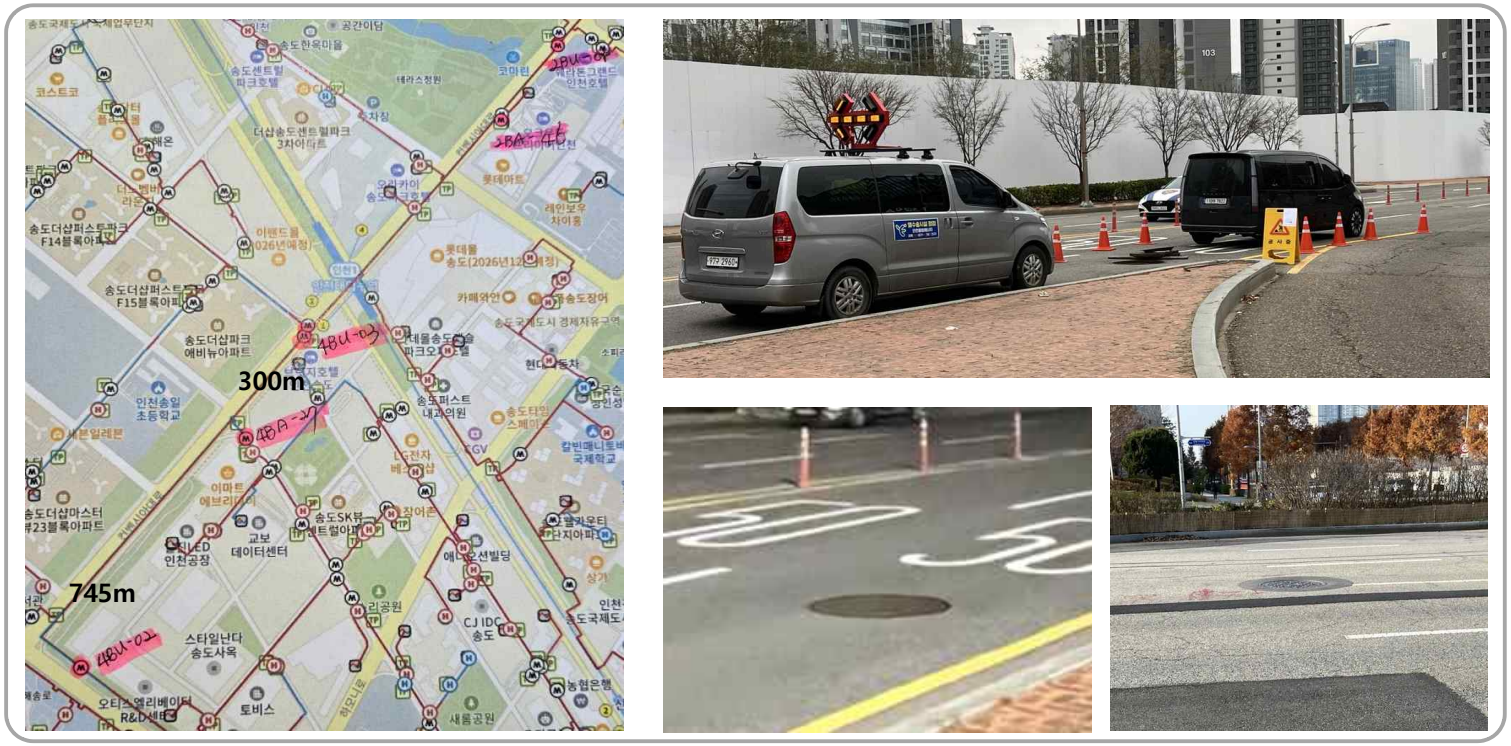
Feature Pump diagnostic equipment

Field measurement scene showing the diagnostic equipment loaded onto a vehicle operating in an urban area, conducting tests at various manholes for district heating pipelines

Structural Health Monitoring & Asset Management

District Heating (DH) Pipelines and Measurement Locations

❑ Manhole Details : 4BU03-supply/return, 4BA27-supply/return, 4BU02-supply pipe



Pipeline Network Map (distance of 4BU03-4BA27 : 745m, distance of 4BA27-4BU03 : 300m) and Manhole Photos

Manhole Preparation and Works Details (cutting a palstic outer pipe, removing polyurethan inslaution to expose the steel pipe underneath)

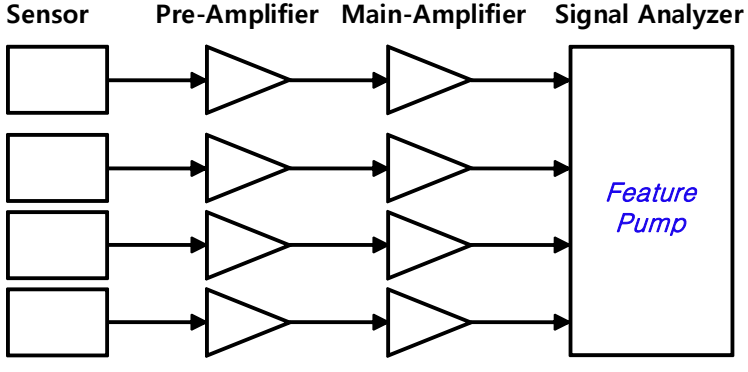
Signal Measurement for DH Pipelines by Measurement Location

❑ Preparation and Installation of Acoustic Emission Sensors



Installation of two specialized AE sensors and signal amplifiers on prepared DH pipelines for data acquisition

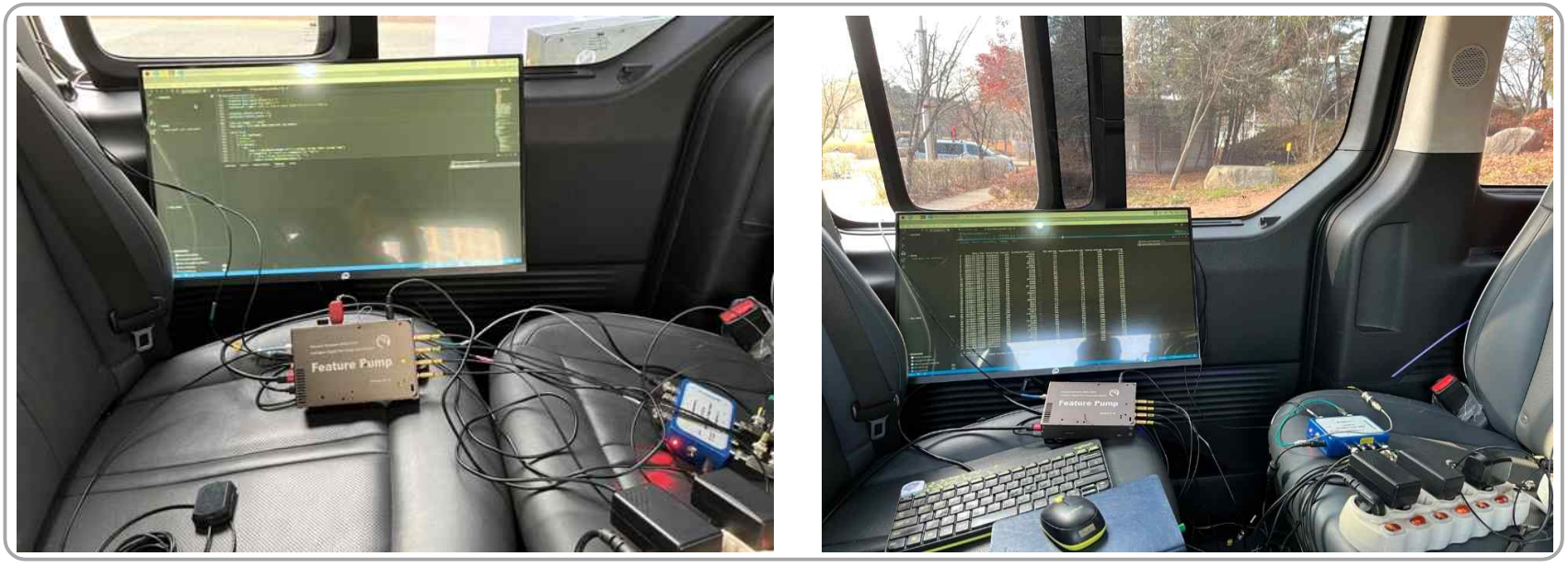
Two specialized AE sensors (Type A and Type C)



Signal Measurement Workflow

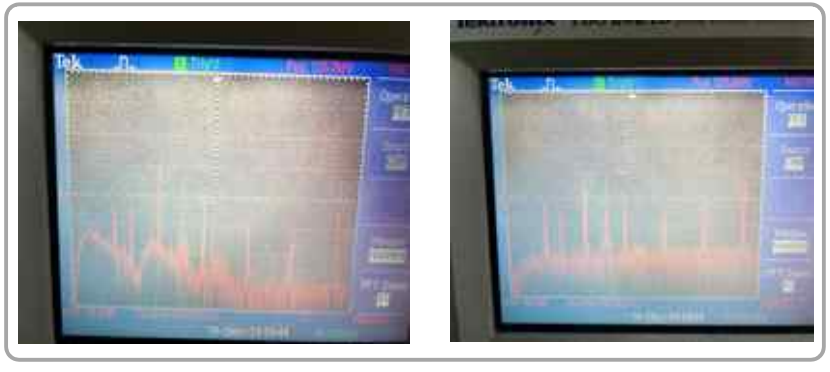
Signal Measurement for DH Pipelines

❑ Verification of Acoustic Emission Signals and Collection of Feature Data



Interior of the measurement vehicle, showing the Feature Pump used for data acquisition, a monitor displaying live data acquisition results

Real-time waveform outputs displayed on analyzer, highlighting the process of capturing raw signals directly form Type A and Type C sensor



Real-time spectral analysis, showing how the spectrum evolves during the measurements, demonstrating the dynamic spectral changes in the signals

Feature Pump Data by Measurement Location

❑ **Continuous signal feature dataset collected over one-second, including spectrum peak statistics, max. amplitude, etc.**

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC
1		Date_Time	FeatureTyp	Channel	InstSpectra	InstSpectra	InstSpectra	InstSpectra	InstSpectra	InstSpectra	AvgSpectra	AvgSpectra	AvgSpectra	AvgSpectra	AvgSpectra	AvgSpectra	AvgSpectra	AvgSpectra	AvgSpectra	AvgSpectra	AvgSpectra	AvgSpectra	AvgSpectra	AvgSpectra	MaxAmplit	RMS_Avera	Magnitude	Energy_Ave	Strength_Average	
2	0	20241215	Continuou	CHC	269312	23	3649536	60	1815583	60	2	30	20	26	14	7857024	46336	45280	43520	31328	27986	250	25775	1185	331	1569	2193	1162	
3	1	20241215	Continuou	CHC	388224	24	3712128	60	1844232	60	2	32	28	18	14	7548000	203584	150944	83776	69952	39232	251	26242	1189	328	1574	2324	1324	
4	2	20241215	Continuou	CHC	376704	24	4007808	60	1995859	60	2	26	30	18	14	7733152	88800	73152	34496	30368	54474	250	16021	1231	344	1578	2484	1441	
5	3	20241215	Continuou	CHC	285952	24	3344384	60	1652239	60	2	18	14	26	30	7963200	90080	75296	65888	50432	39339	245	28752	1227	347	1583	2277	1762	
6	4	20241215	Continuou	CHC	274432	24	3486848	60	1735305	60	2	18	26	14	30	7964736	175872	133920	93824	76544	3143	250	37589	1168	349	1587	2229	1526	
7	5	20241215	Continuou	CHC	278528	24	3750400	60	1870480	60	2	26	30	20	14	2685312	75328	69024	47040	37600	61306	252	41813	1227	342	1592	2148	1619	
8	6	20241215	Continuou	CHC	385664	24	3663360	60	1815968	60	2	18	26	14	30	3269776	140896	116416	113056	66512	57096	249	23407	1184	340	1597	2136	1737	
9	7	20241215	Continuou	CHC	277888	24	4029568	60	2004068	60	2	36	26	18	14	4137024	85152	42816	38048	31712	12096	246	21922	1209	343	1602	2338	1616	
10	8	20241215	Continuou	CHC	291200	24	3704704	60	1833475	60	2	36	30	26	18	7610208	88320	48992	48864	41600	55352	245	1028	1228	352	1606	2036	1726	
11	9	20241215	Continuou	CHC	402432	24	2806144	60	1378664	60	4	18	34	26	30	1858160	183504	167888	155664	76320	49503	248	4902	1200	347	1611	1950	1567	
12	10	20241215	Continuou	CHC	287488	24	3935872	60	1954401	60	4	20	36	30	26	11032704	133984	87584	42464	41792	6699	248	59427	1203	342	1616	2133	1673	
13	11	20241215	Continuou	CHC	402688	56	3976960	60	1981251	60	4	34	20	26	30	11595120	90832	86944	70048	52512	31161	243	24100	1203	352	1621	2148	1685	
14	12	20241215	Continuou	CHC	376320	24	3969408	60	1964928	60	4	18	36	26	30	11349344	127008	86016	46688	45792	14916	247	24236	1196	344	1625	1953	1712	
15	13	20241215	Continuou	CHC	285568	24	3397376	61	1697806	61	4	34	30	26	20	11305792	99056	72880	41328	39632	52374	249	55850	1203	349	1630	2059	1750	
16	14	20241215	Continuou	CHC	293760	24	3266176	60	1628634	60	4	18	36	30	26	11416304	261712	88256	50672	49136	10077	240	53589	1197	341	1635	2232	1646	
17	15	20241215	Continuou	CHC	286336	24	3517824	60	1748240	60	4	34	42	26	30	11098656	125024	115968	106176	55872	44910	240	43943	1228	356	1639	2188	1665	
18	16	20241215	Continuou	CHC	367488	24	2899328	60	1441410	60	4	34	26	30	18	10466928	164672	144688	103504	86768	29404	248	2491	1228	336	1649	2250	1591	
19	17	20241215	Continuou	CHC	281216	24	4186496	60	2070665	60	4	36	46	26	30	9313440	79040	47040	43296	42656	53848	246	50208	1242	339	1654	2031	1522	
20	18	20241215	Continuou	CHC	386816	25	3546624	60	1764700	60	2	36	18	30	26	408640	78368	46624	40800	40512	63095	244	7842	1232	328	1663	2445	1559	
21	19	20241215	Continuou	CHC	380416	24	3704832	60	1827220	60	2	26	30	18	14	7403280	44352	42688	36096	32144	40497	248	51735	1231	326	1668	2218	1562	
22	20	20241215	Continuou	CHC	286336	24	4189184	60	2084833	60	4	26	30	36	20	811680	238464	107360	84384	40160	27374	245	49609	1211	353	1672	2321	1563	
23	21	20241215	Continuou	CHC	349184	17	3784576	60	1879650	60	2	18	14	26	30	7462720	140544	93760	44704	44544	39824	245	10809	1199	333	1677	2160	1614	
24	22	20241215	Continuou	CHC	270976	24	4093952	60	2029932	60	2	18	26	30	14	7815536	122240	50944	49792	35232	39273	249	47139	1185	357	1682	2260	1483	

Excel sheets displaying continuous feature data from Feature Pump (Channel B/D), measured over 2 hours with 400 datasets

❑ **Transient signal feature dataset collected over half-second with 500us HDT/HLT, including first hits and max-amplitude hits**

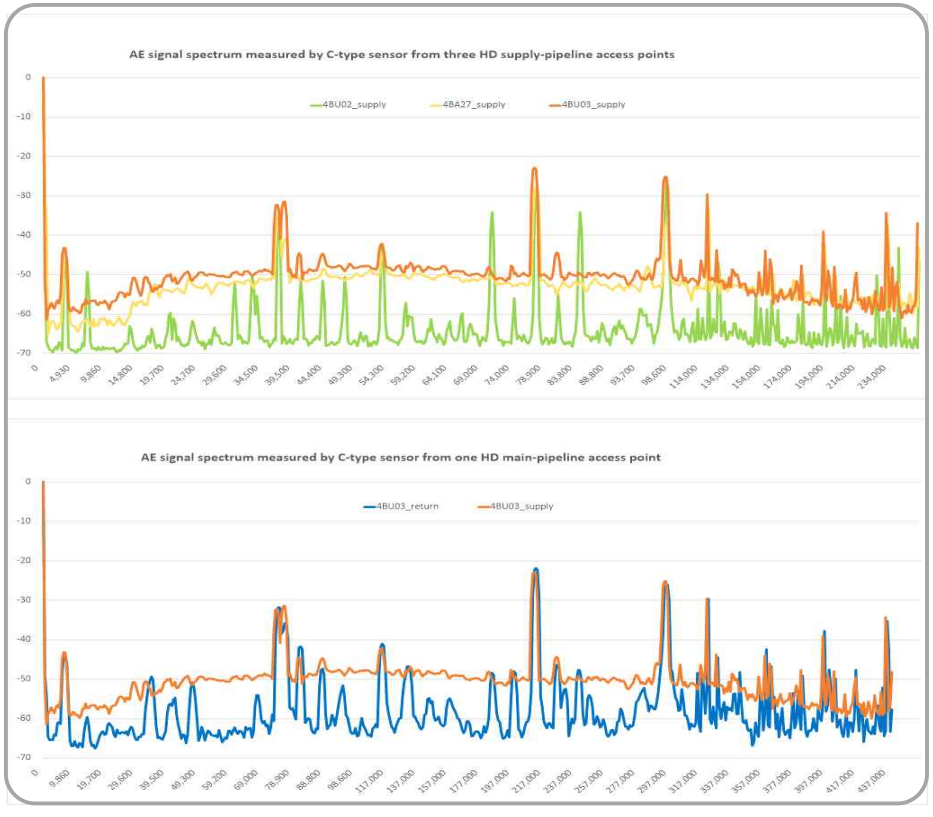
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC
1		Date_Time	FeatureTyp	Channel	UTC_Secor	Stamp_Init	Initial_Amp	Initial_Dura	Initial_Risin	Initial_Ring	Initial_InitC	Initial_AbsE	Initial_Ener	Initial_Strer	Initial_RMS	Stamp_Ma	Maximum	Duration_C	RisingTime	RingCount	InitCount_(	AbsEnergy_	Energy_Of_	Strength_C	RMS_Of_M	Median_An	Median_RN	Hit Rate		
2	0	20241215	Transient	CHD	20863	330224	17293	62.4	0.3	134	116	7571606	10360135	8643648	182	603081	20440	62.4	0.2	128	1	7750788	24493576	8650512	288	11776	186	87	
3	1	20241215	Transient	CHD	20863	340714	10532	62.4	53.7	140	5	7515394	2063586	4923360	281	349266	20426	62.4	0.3	138	0	5610792	23626486	9204000	154	11776	196	89	
4	2	20241215	Transient	CHD	20863	361118	20302	62.4	0	146	118	7229505	11445213	5928624	26	361118	20302	62.4	0	146	118	7229505	11445213	5928624	26	11264	189	89	
5	3	20241215	Transient	CHD	20863	371640	11440	62.4	13	135	26	5041519	30632479	4891536	276	521842	20564	62.4	0.3	135	0	7813117	345784	8890752	289	12800	215	88	
6	4	20241215	Transient	CHD	20863	380192	13307	62.4	48.8	145	113	3765956	6511811	4962048	273	42534	21101	62.4	42.8	142	100	5523148	3152667	7046208	162	12032	194	88	
7	5	20241215	Transient	CHD	20863	392016	7463	62.4	0.2	145	142	2240286	1960101	7453056	62	22764	18873	62.4	0.3	130	1	5668040	2081312	8233056	116	11520	188	89	
8	6	20241215	Transient	CHD	20863	400570	7150	62.4	0.2	135	58	6976788	11351060	7436208	269	33827	21308	62.4	29.1	141	63	6654357	15808310	7734480	144	11520	191	86	
9	7	20241215	Transient	CHD	20863	409116	20024	62.4	0.2	125	76	7313316	18246918	7536672	87	409116	20024	62.4	0.2	125	76	7313316	18246918	7536672	87	12288	183	86	
10	8	20241215	Transient	CHD	20863	417665	7158	62.4	0.3	129	106	7565392	15407961	7259616	206	575083	18399	62.4	0.3	132	0	3041478	8603512	7985328	228	11264	198	90	
11	9	20241215	Transient	CHD	20863	429309	7343	62.4	2	138	18	5526456	8295976	5098704	56	468193	18054	62.4	0.3	125	1	4897884	14382192	7602816	161	11264	186	88	
12	10	20241215	Transient	CHD	20863	440013	6681	62.4	0.1	130	29	8406592	15067638	5786352	222	455759	18110	62.4	0.3	118	0	8236040	31337460	8403408	59	11264	193	89	
13	11	20241215	Transient	CHD	20863	450514	10084	62.4	53.8	128	1	3555267	12536942	5001360	276	91893	20644	62.4	57.5	143	132	1637760	21141917	6805344	272	12032	196	89	
14	12	20241215	Transient	CHD	20863	472686	12532	62.4	61.9	137	29	9007779	855937	4660656	171	133144	20348	62.4	0.3	129	1	7838406	11306144	8117616	220	12288	191	87	
15	13	20241215	Transient	CHD	20863	481271	13280	62.4	58.7	147	2	5928386	1846216	4632576	145	138589	21152	62.4	37.1	142	86	2330212	6254148	7196592	262	12288	197	87	
16	14	20241215	Transient	CHD	20863	491099	8240	62.4	6.2	131	78	2563778	9349587	4981392	218	508998	21132	62.4	0.3	132	1	5522395	24170384	8455200	266	11776	195	86	
17	15	20241215	Transient	CHD	20863	499660	21051	62.4	3.6	147	114	9472172	31776952	4936464	187	499660	21051	62.4	3.6	147	114	9472172	31776952	4936464	187	12288	192	86	
18	16	20241215	Transient	CHD	20863	510357	7413	62.4	0.1	140	2	3940704	3270501	6276192	168	188334	21652	62.4	0.3	130	1	6472255	26046368	8922576	280	12800	209	87	
19	17	20241215	Transient	CHD	20863	520847	11188	62.4	55.4	140	14	4710737	2408792	4967040	41	167352	14607	62.4	55.4	136	119	1536099	29917842	4961424	289	11264	195	89	
20	18	20241215	Transient	CHD	20863	529432	11603	62.4	61.9	140	1	1685063	21755707	4997616	278	55264	22071	62.4	51.8	148	122	7929640	31356683	6911424	85	12800	196	88	
21	19	20241215	Transient	CHD	20863	541253	7252	62.4	0.3	134	114	8575425	20014172	5799456	198	213982	21090	62.4	0.3	137	1	8551740	19051968	8798400	289	12032	199	88	

Excel sheets displaying transient feature data from Feature Pump (Channel A/C), measured over 2 hours with 800 datasets

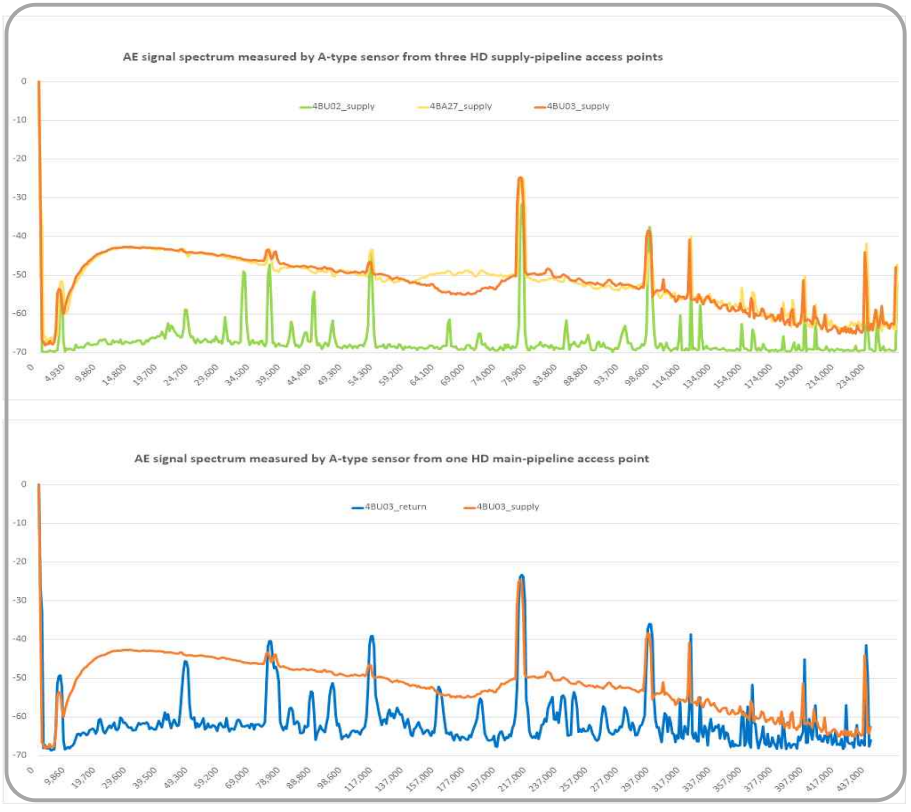
Spectrum Analysis of Sensor Signals by Measurement Location

❑ Spectrum Analysis and Review of Acoustic Emission Signals Per Measurement Location :

Selection of relevant frequency bands (1), Evaluation of corrosion levels in the pipelines through the spectral analysis (2), Establishing new criteria of leakage detection using peak frequencies and magnitudes (3)

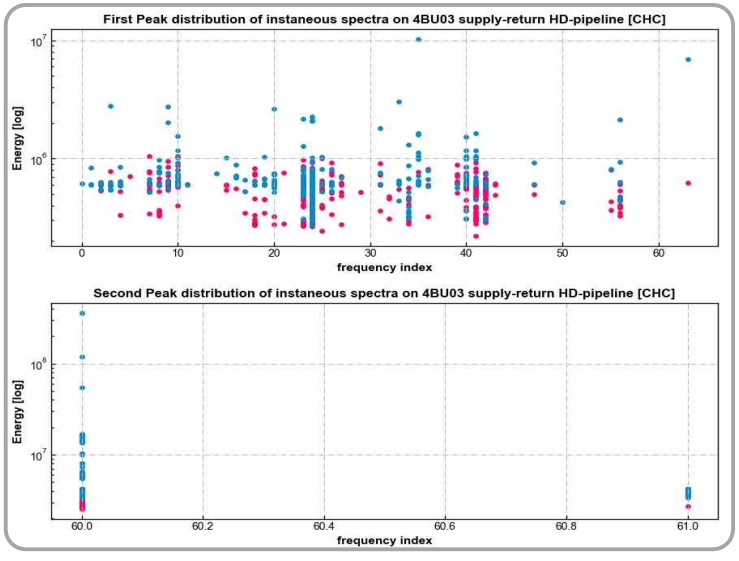


Spectral curves of AE signals from C sensor (upper: 02S/27S/03S manholes, low: 03S/03R manholes)

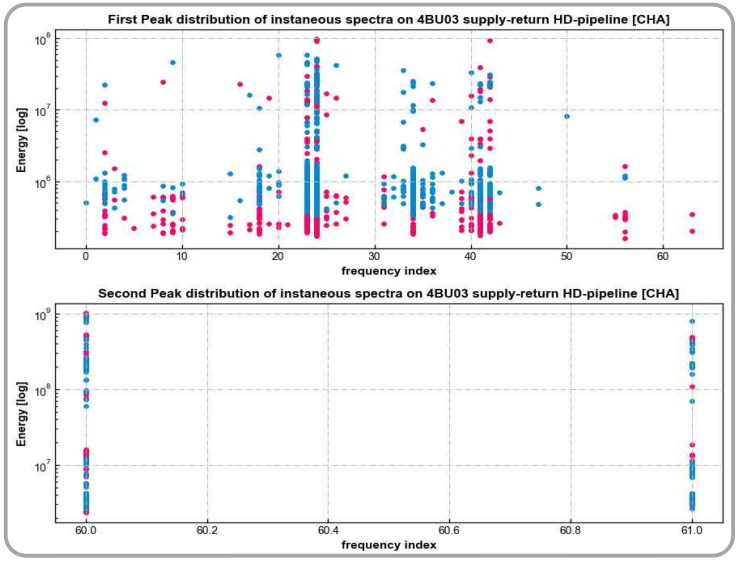


Spectral curves of AE signals from A sensor (upper: 02S/27S/03S manholes, low: 03S/03R manholes)

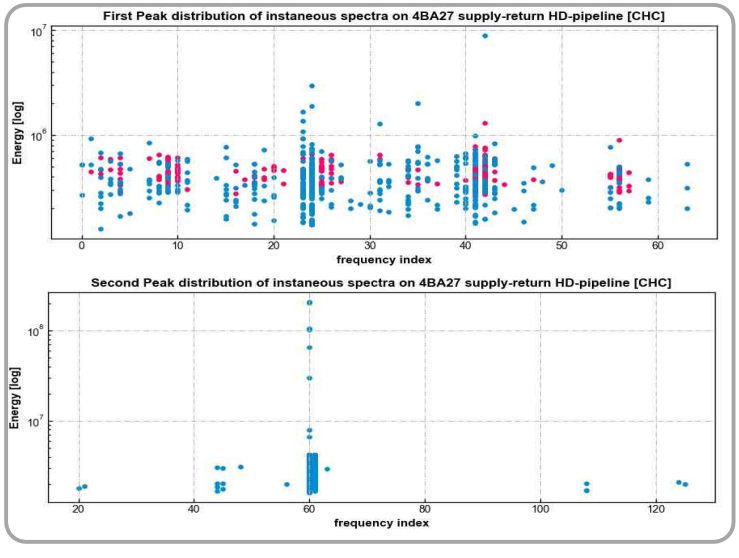
Instantaneous-Spectrum (IS) Peak Distribution by Measurement Location



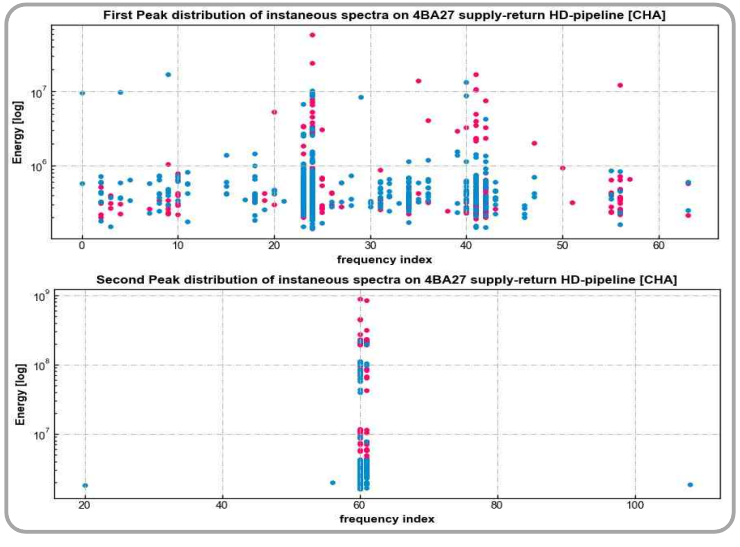
IS Peak distribution of C sensor at 4BU03-S/R pipelines



IS Peak distribution of A sensor at 4BU03-S/R pipelines

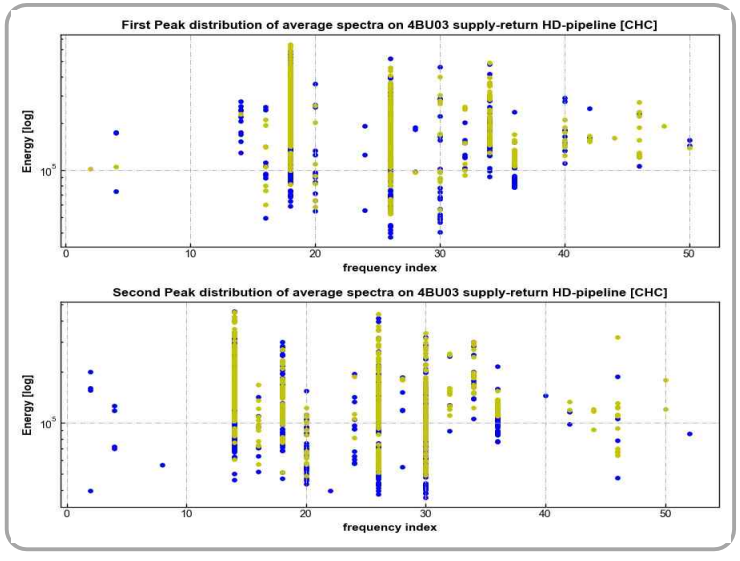


IS Peak distribution of C sensor at 4BA27-S/R pipelines

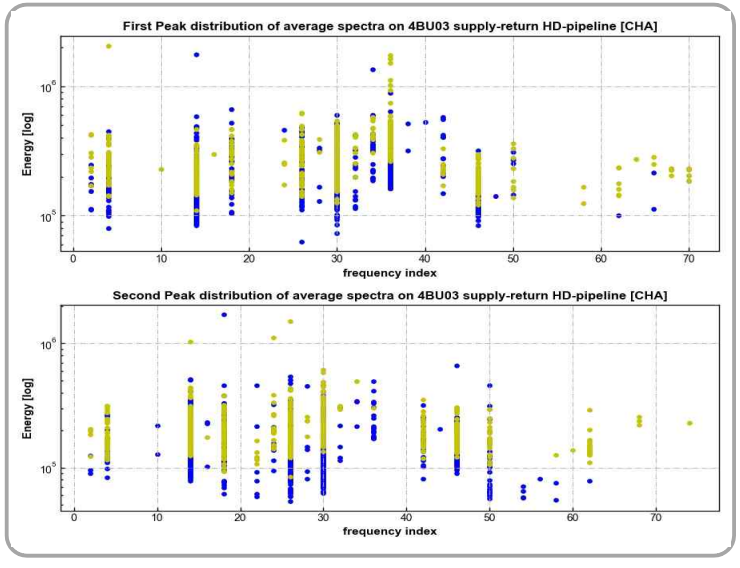


IS Peak distribution of A sensor at 4BA27-S/R pipelines

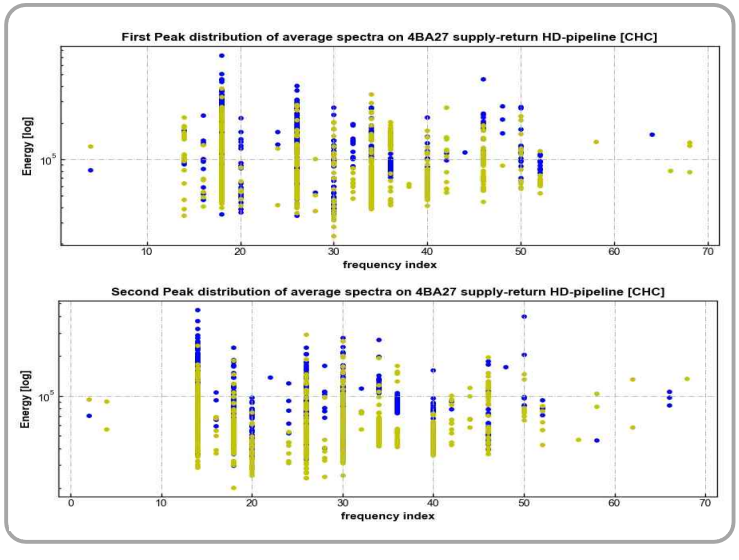
Averaged-Spectrum (AS) Peak Distribution by Measurement Location



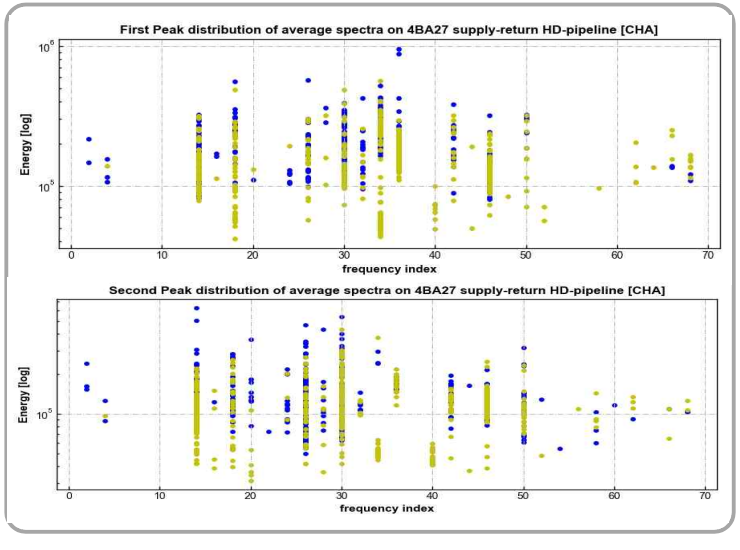
AS Peak distribution of C sensor at 4BU03-S/R pipelines



AS Peak distribution of A sensor at 4BU03-S/R pipelines

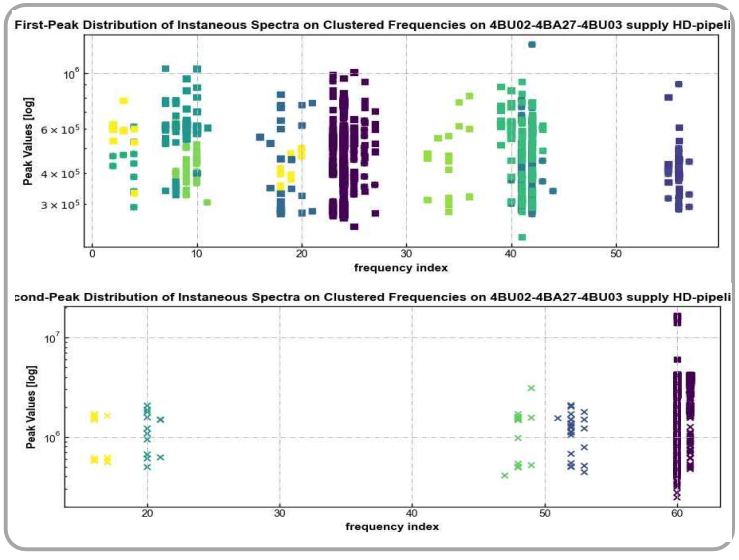


AS Peak distribution of C sensor at 4BA27-S/R pipelines

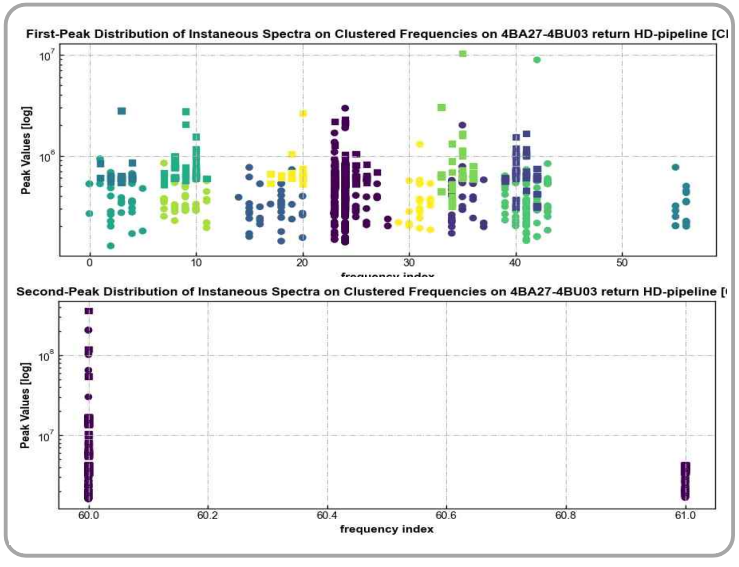


AS Peak distribution of A sensor at 4BA27-S/R pipelines

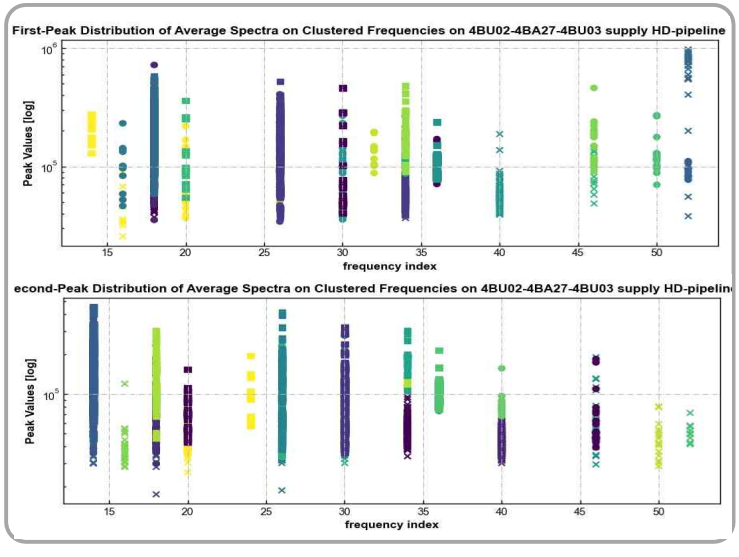
Cluster Distribution of AI Spectrum Peak Patterns



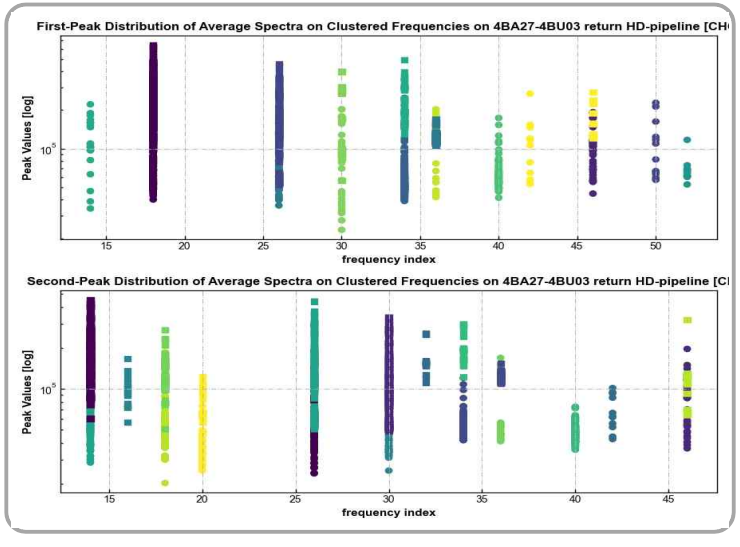
IS Peak pattern clusters of C sensor



IS Peak pattern clusters of A sensor

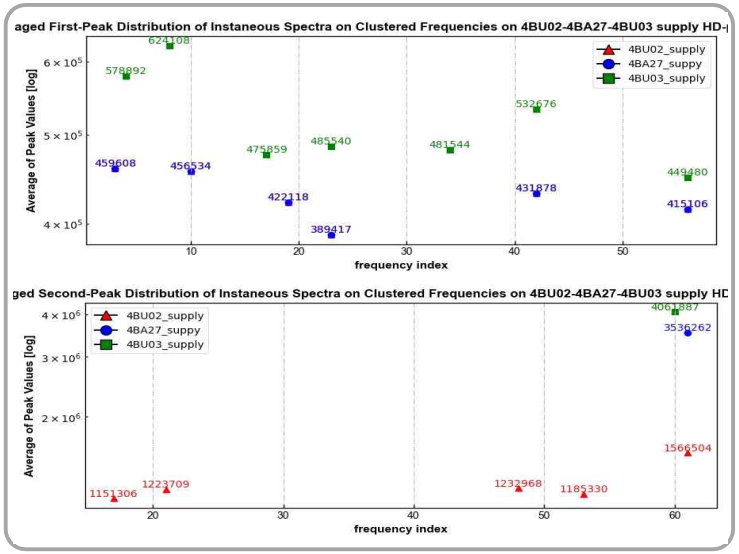


AS Peak pattern clusters of C sensor

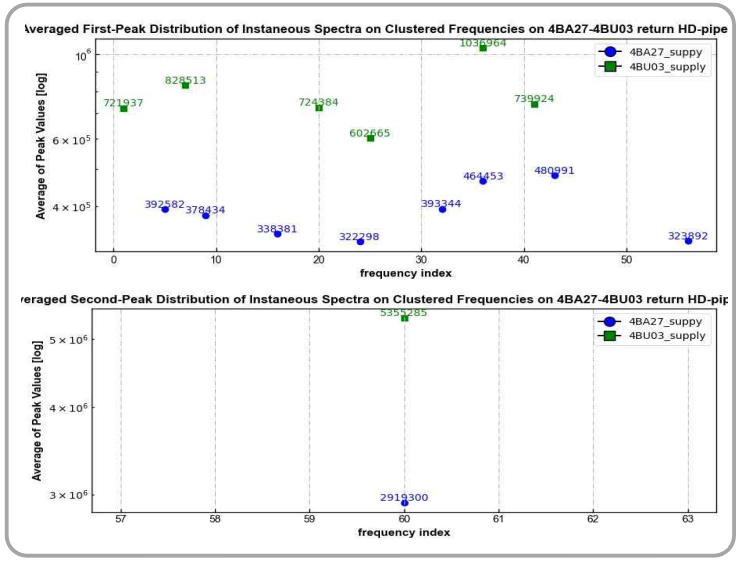


AS Peak pattern clusters of A sensor

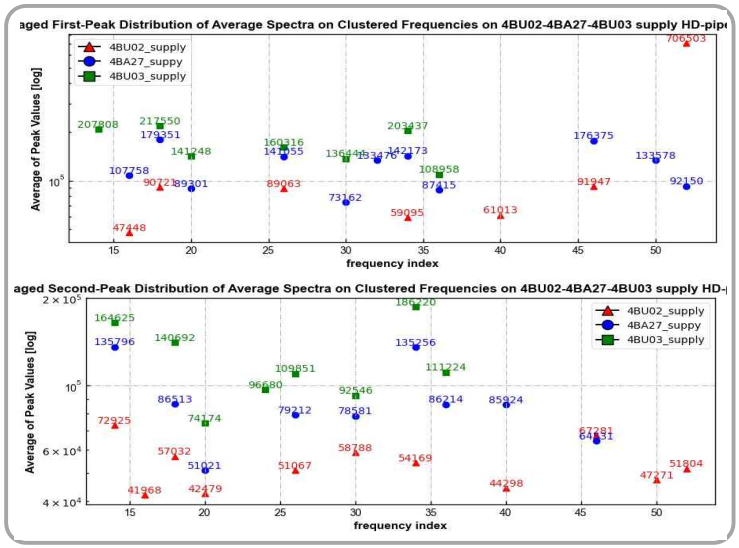
Cluster Statistics of AI Spectrum Peak Patterns



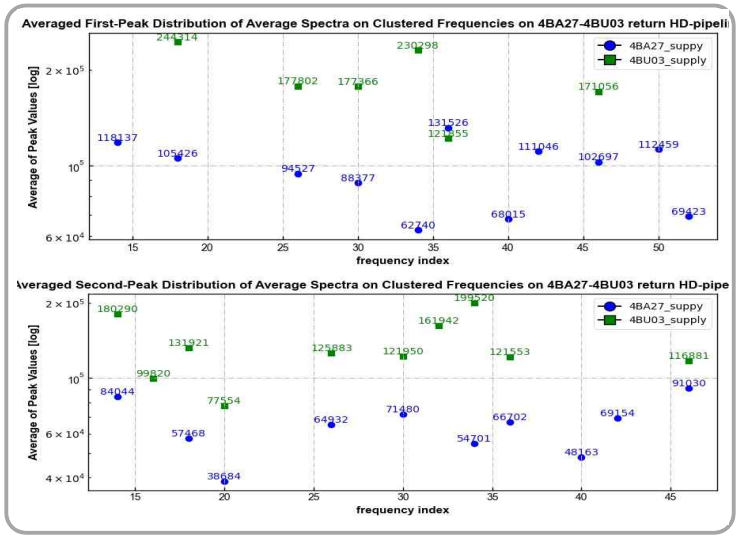
IS Peak cluster averages of C sensor



IS Peak cluster averages of A sensor

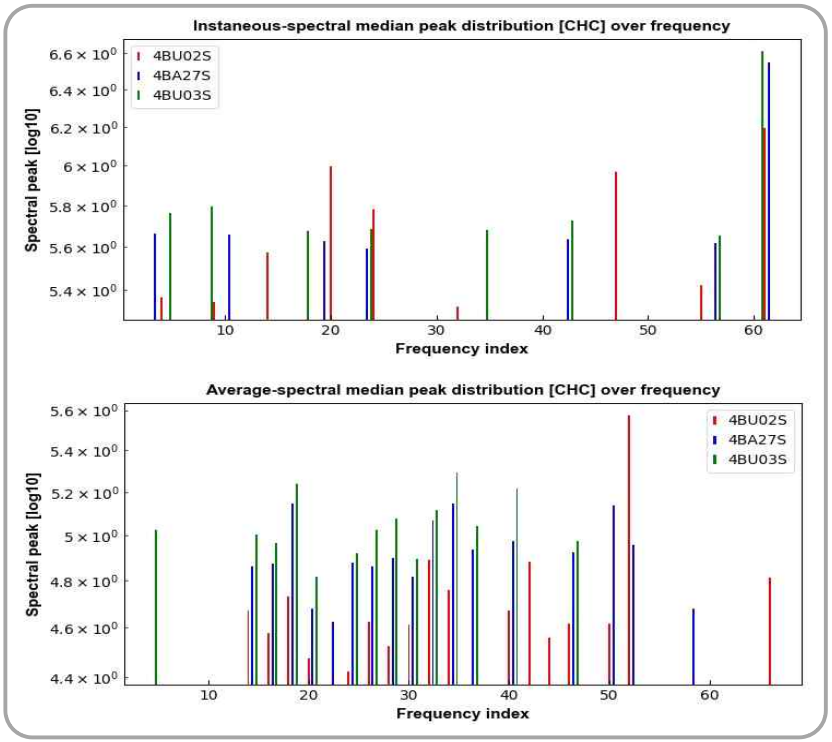


AS Peak cluster averages of C sensor

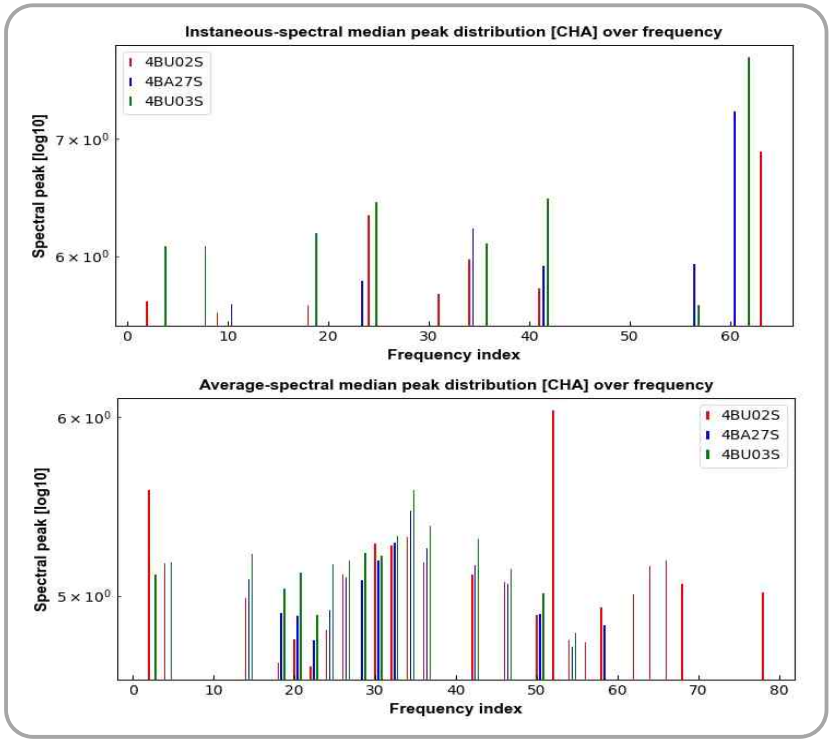


AS Peak cluster averages of A sensor

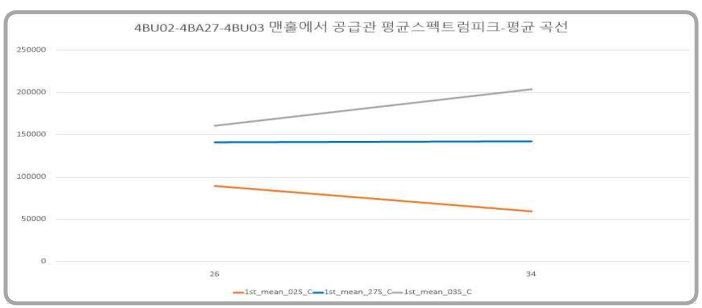
Distribution of Clustered-Peaks Averages by Measurement Location



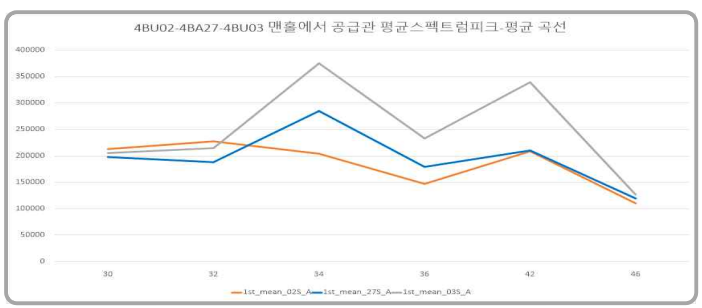
Distribution of clustered-AS-peaks averages of C sensor



Distribution of clustered-AS-peaks averages of A sensor

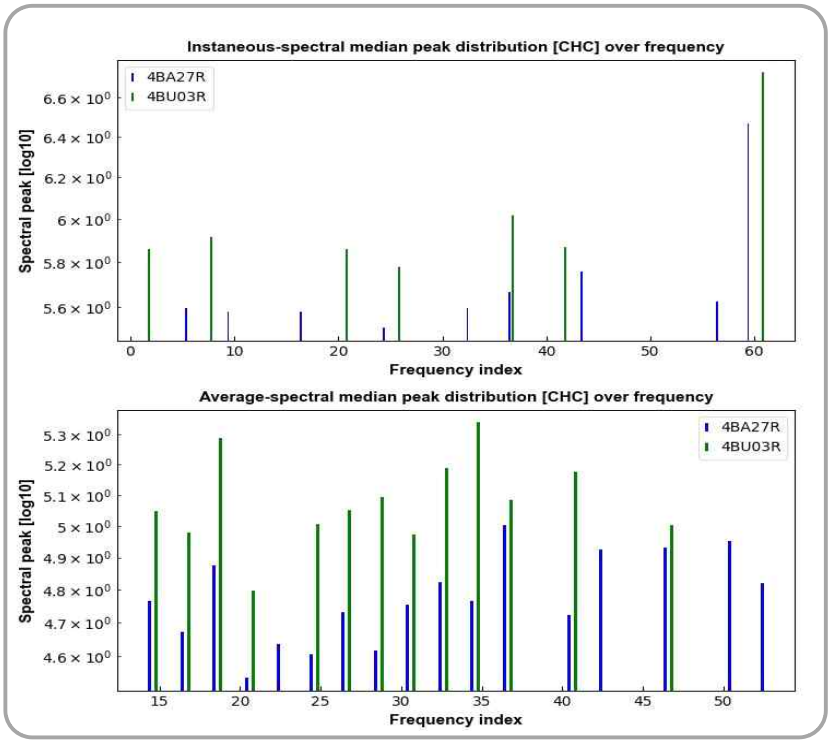


Total average values of clustered-AS-peaks of C sensor

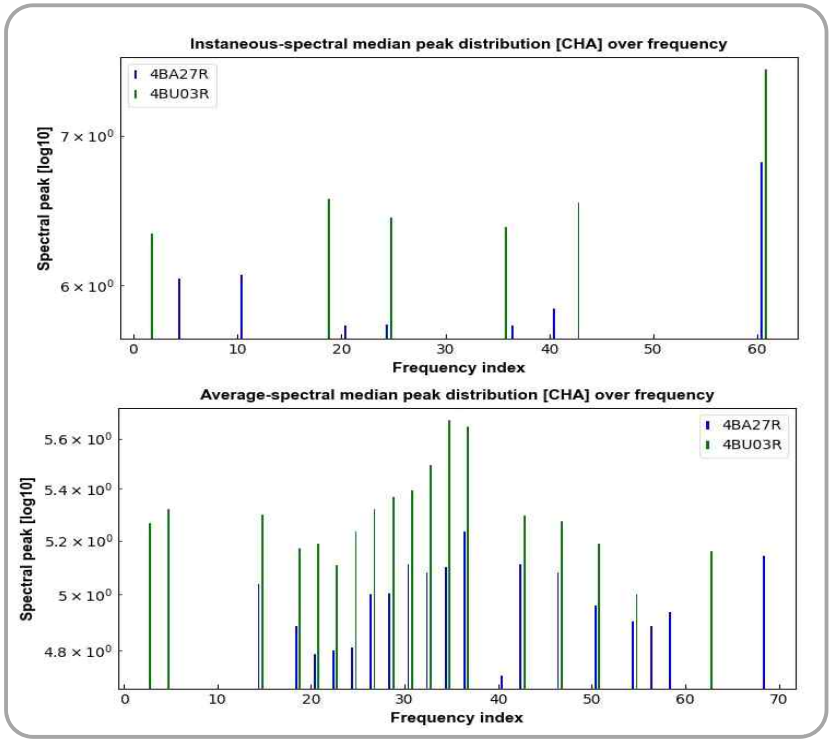


Total average values of clustered-AS-peaks of A sensor

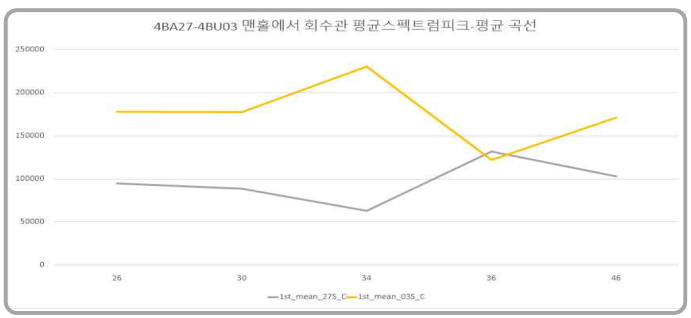
Distribution of Clustered-Peaks Averages by Measurement Location



Distribution of clustered-IS-peaks averages of C sensor

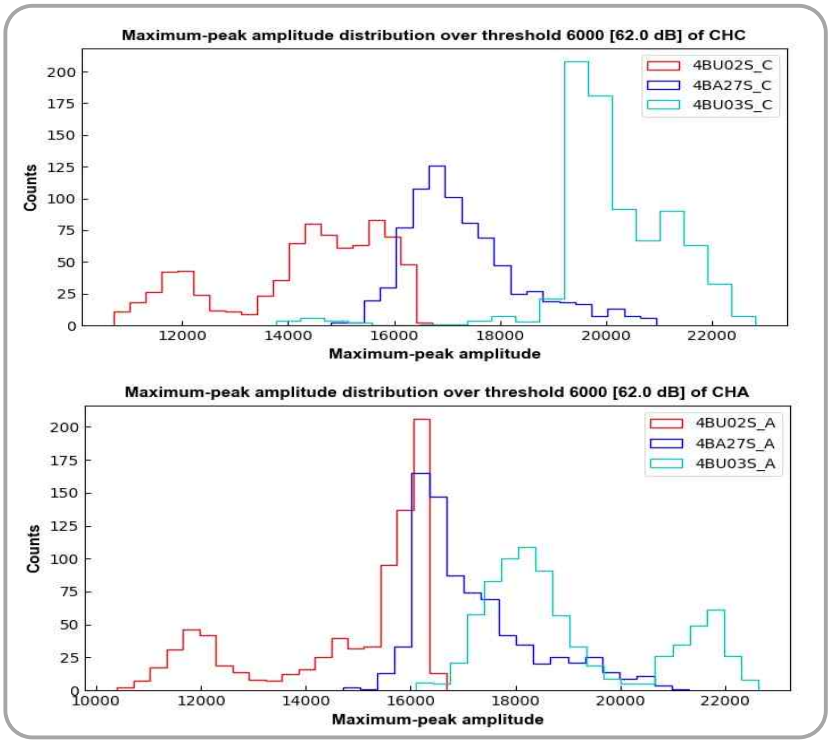


Distribution of clustered-IS-peaks averages of C sensor

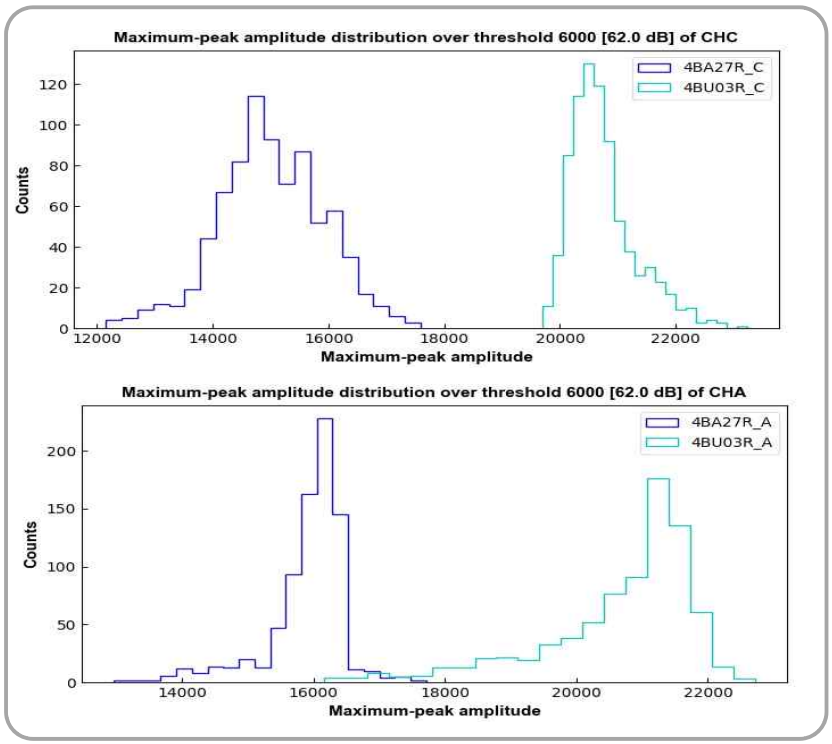


Total average values of clustered-IS-peaks of C sensor

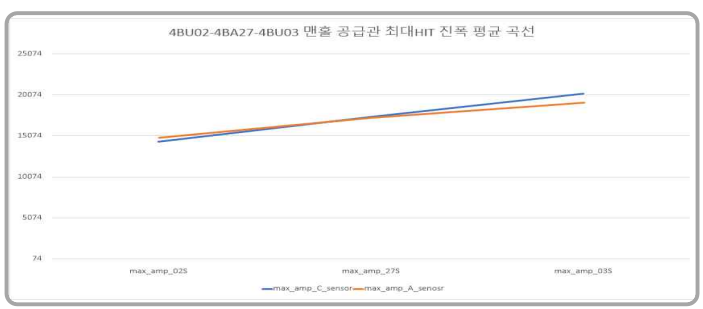
Amplitude Distribution of Max-Amplitude Hits by Measurement Location



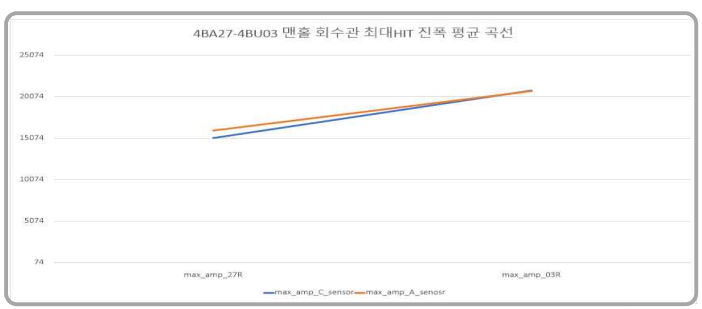
Amplitude distribution of max-amplitude hits in the supply pipelines



Amplitude distribution of max-amplitude hits in the return pipelines

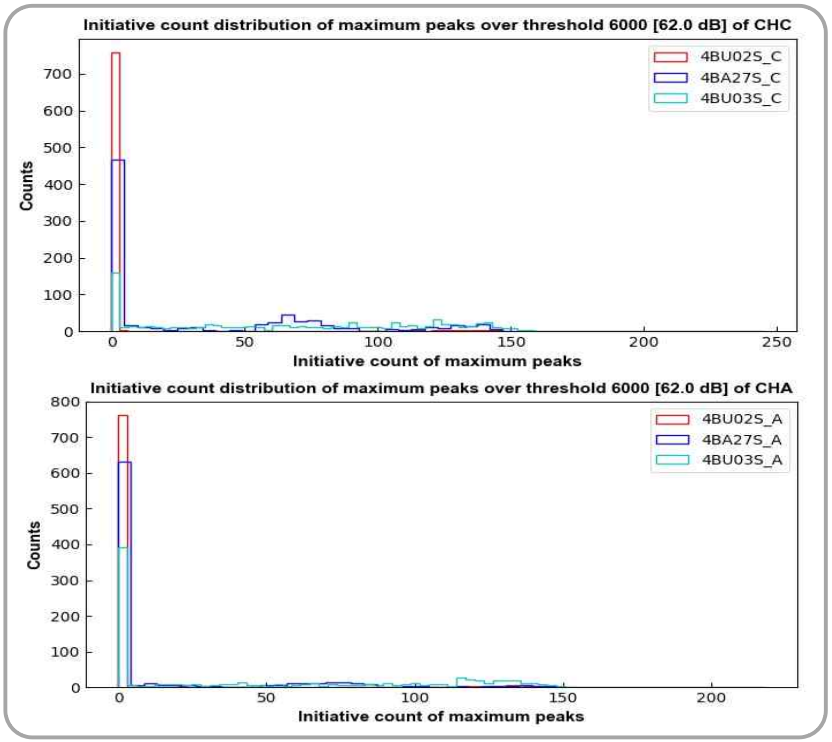


Amplitude mean values of max-amplitude hits in the supply pipelines

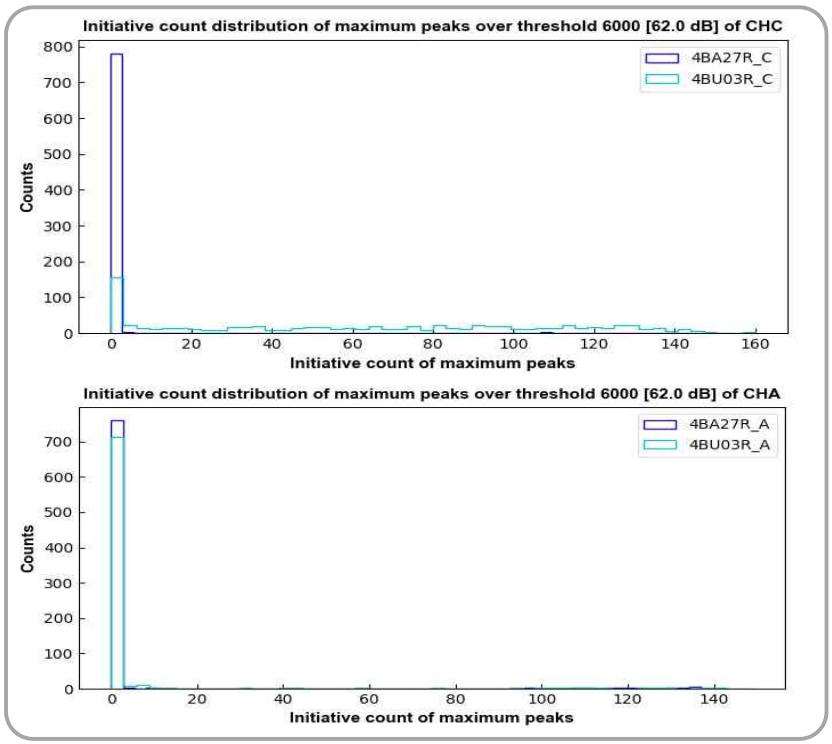


Amplitude mean values of max-amplitude hits in the return pipelines

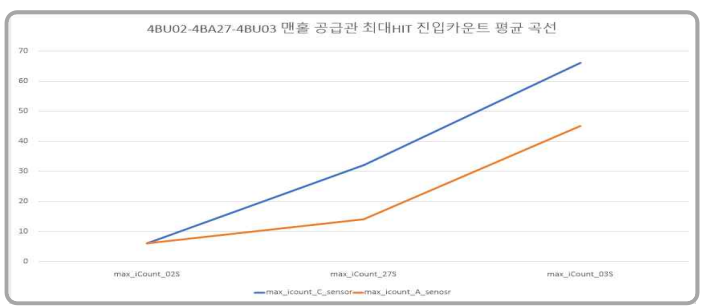
Initiative Counts of Max-Amplitude Hits by Measurement Location



Init-count distribution of max-amplitude hits in the supply pipelines

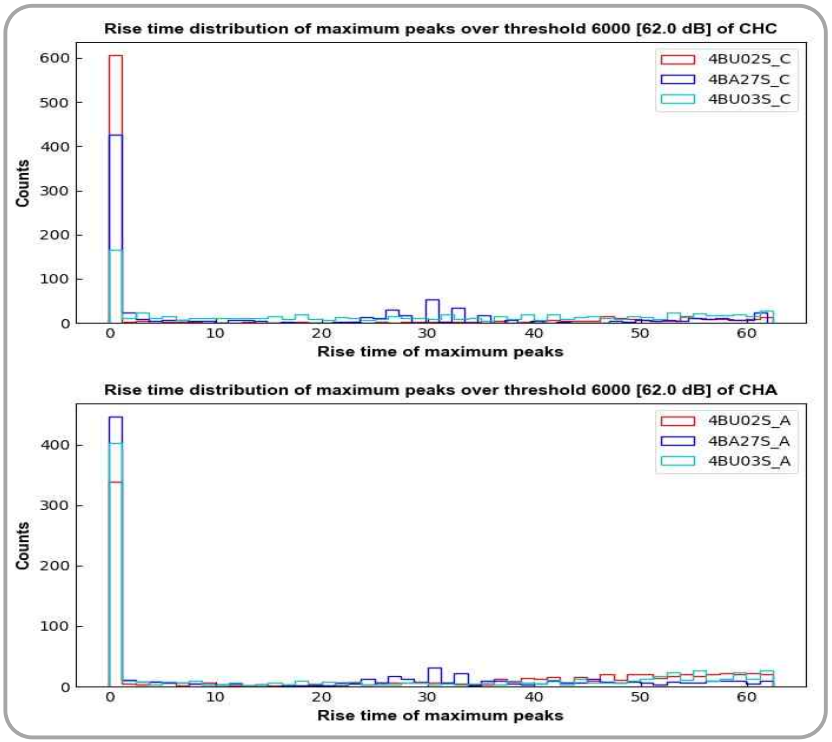


Init-count distribution of max-amplitude hits in the return pipelines

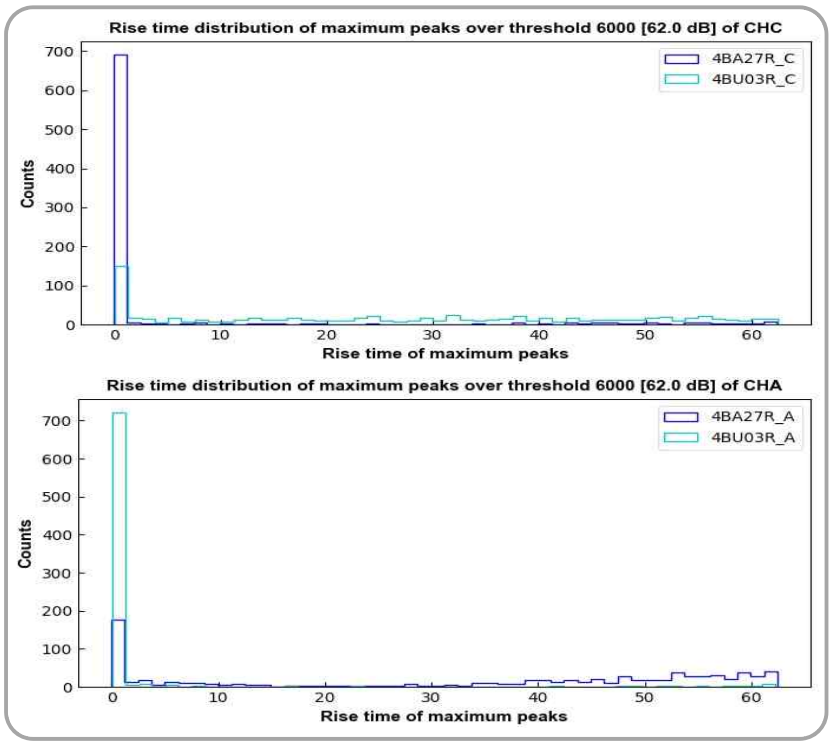


Init-count mean values of max-amplitude hits in the supply pipelines

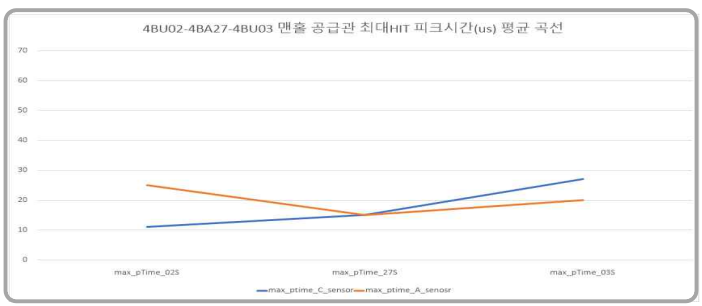
Rising Times of Max-Amplitude Hits by Measurement Location



Rising-time distribution of max-amplitude hits in the supply pipelines

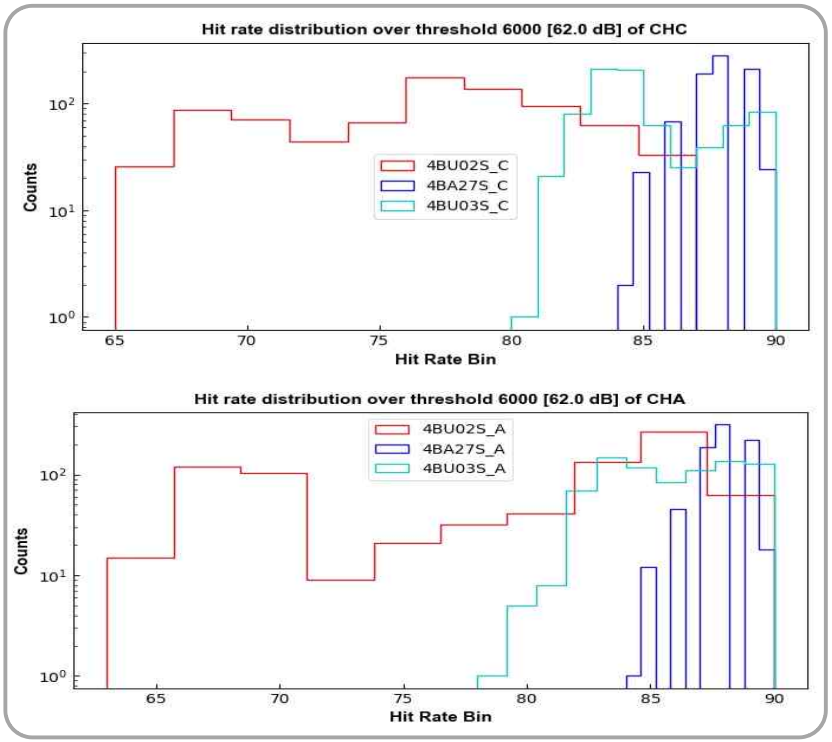


Rising-time distribution of max-amplitude hits in the return pipelines

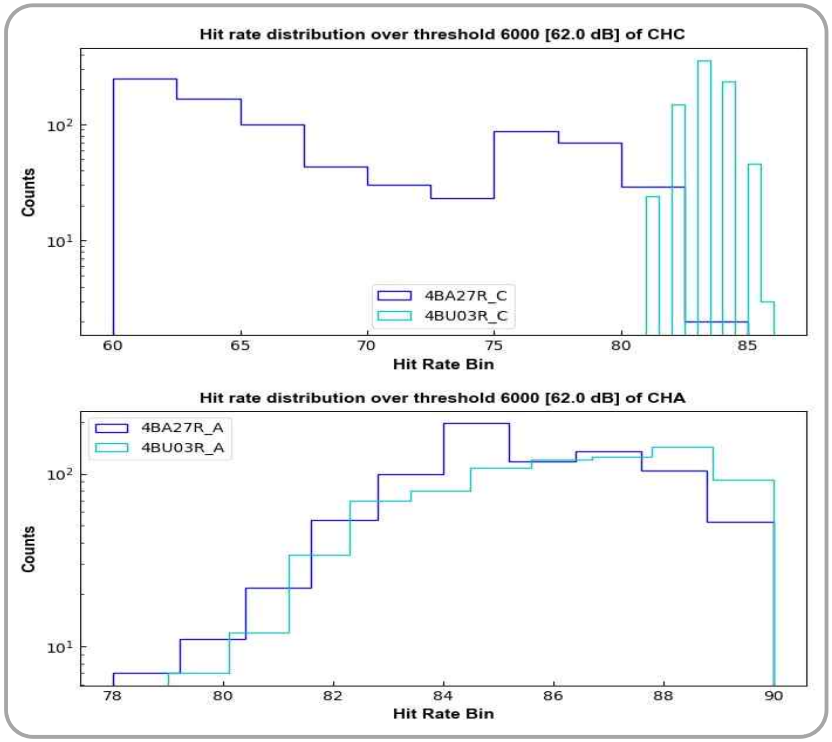


Rising-time mean values of max-amplitude hits in the supply pipelines

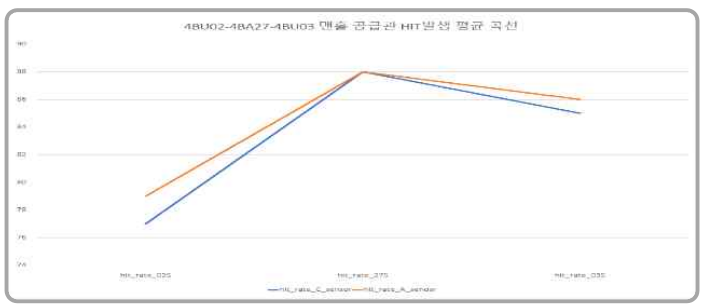
Hit Rate Distribution of Sensor Signals by Measurement Location



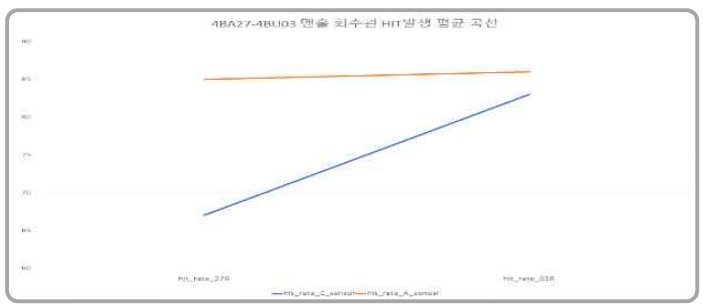
Hit-rate distribution in the supply pipelines



Hit-rate distribution in the return pipelines



Hit-rate mean values in the supply pipelines



Hit-rate mean values in the return pipelines

Health Condition Assessment of DH pipelines

❑ AE Test Procedure: International Standards ASME Section V and ASTM E569 Test Measurement and Evaluation

❑ Intensity analysis in feature data (ASTM-E-569)

❑ Pattern analysis of SecureAI, Inc.

❑ Analysis results of AE activity and intensity by the measurement location

Location (Manhole-Pipeline)	4BU02S	4BA27S	4BU03S	4BU03R	4BA27R
Hit Rate (Type C/ Type A)	77 / 79	88 / 88	85 / 86	83 / 86	67 / 85
Amp. Averages of AE Hits	14266	17302	20127	20729	15011

❑ Risk grade and post-action recommendation of the DH pipelines

Grade	Specific Location (Pipelines)	Health Condition, Recommendations
N/A	-	AE Hit is less than 10 (evaluation not required)
Insignificant	-	Insignificant AE results
A	-	Minor defects, record for future testing
B	4BU02-supply, 4BA27-return	Surface defect(Corrosion, Pitting), Visual Inspection
C	4BA27-supply, 4BU03-supply, 4BU03-return	Surface defect, IoT Continuous Monitoring and UT
D	-	Significant defect (initial leakage), MT & UT
E	-	Critical defect, Immediate MT & UT

IoT Continuous Health Monitoring of DH pipelines

Need for IoT continuous health monitoring and diagnosis

- ❑ Frequent occurrence of high-temperature water leakage accidents in long-term use
- ❑ Accelerated aging of DH pipelines for over 20 years
- ❑ Limitation of existing diagnostic methods such as temperature-sensing wires, etc.
- ❑ On-site inspection securing personnel, and preventing traffic accidents
- ❑ Occurrence of supply disruption during winter due to suspension of hot water supply

DH pipelines requiring IoT continuous inspection

- ❑ Large-diameter DH pipelines with significant impact on industry in case of leaks
- ❑ DH pipelines in vulnerable sections that require daily on-site inspection

IoT Continuous Inspection AI Solutions

- ❑ Product Contents : (1) two special sensors (2) IoT FeaturePump (3) GIS dashboard
- ❑ Service Contents : real-time leakage detection and corrosion status evaluation

Reducing Operational Costs with IoT Feature Pump Diagnosis

Achieving Over 70% Cost Reduction in Opearational Expense for DIstrict Heating Pipelines

❑ Lifecycle Operational and Maintenace Costs of Traditional On-Site Diagnosis

(1) Daily Vulnerable Point Check
(2) 12 Inspections of Key Zones
(3) 6 Inspections of Safety Zones

- On-Site Inspection Costs with Theraml Camera, DCVG etc. Replacement/Repair Costs
- Significant On-Site Labor and Safety Costs : One-SIte Inspection Personnel, Diagnostic Equipment Purchase Costs
- Inspection Costs for Critical Sections over 20 Years : 700,000 ~ 150,000 USD

❑ Lifecycle Opeational and Maintenance Costs of IoT-based Leakage, Corrosion Status Continuous Diagnostics

- Condition-Based Maintenance and Real-Time Inspections (Independent of Inspection Intervals)
- Operational Costs for Installed Sections Over 20 Years : 200,000 ~ 400,000 USD
- Significant Reduction in DH pipeline Repair Costs through Preventive Measures with IoT FeaturePump Diagnosis

❑ Lifecycle Cost Breakdown: Initial Installation, Preventive Maintenace of Minor/Major Defects, Replacement Costs

❑ The cost analysis reflects the impact on DH pipeline aging and the effectiveness of diagnostic methods

❑ Characteristics: Increased Defect Frequency, Rapid Rise in Minor Defects, Fast Escalation from Minor to Major Defects

❑ IoT FeaturePump Continuous Diagnostics : Detection of Minor Defects, Fast Defect Detection Time (Responsiveness)