USER CASE STUDY ABSTRACT

20th International Pump Users Symposium

TITLE:

Reliability Improvement of End Suction Pump in Severe Service through Engineered Component Upgrade

ABSTRACT:

An end suction pump for amine service at an Ammonia plant was successfully upgraded by improvement of its components.

Two 290 kW (390 HP) pumps, turbine/motor driven, rated for 262 m^3/hr (1,153 gpm) and 271 m (889 ft), operate in severe service conditions due low NPSHA and part-load operation. The equipment exhibited rough operation with high vibration and an elevated repair frequency by recurrent fatigue failure of shaft, severe wear ring rubs, impeller corrosion/erosion, mechanical seal leakage and bearing damages..

After a catastrophic failure, involving pump and electric motor, that caused an emergency plant shutdown, an upgrade for the pumps was engineered. The objective was to overcome design weaknesses and incorporate features to increase reliability. Impeller deficiencies were identified and corrected and its metallurgy improved to endure severe cavitation/recirculation damage. The power end was completely redesigned, incorporating larger shaft and bearing housing stiffness, together with a material upgrade, oversized bearings and lubrication enhancements.

As a result, a failure frequency as large as 9 a year has been eliminated since the upgrade and the pump presently accumulates 3 years of continuous operation. An outstanding improvement in reliability was obtained together with considerable savings in investment & maintenance costs.

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RELIABILITY IMPROVEMENT OF END SUCTION PUMP IN SEVERE SERVICE THROUGH ENGINEERED COMPONENT UPGRADE

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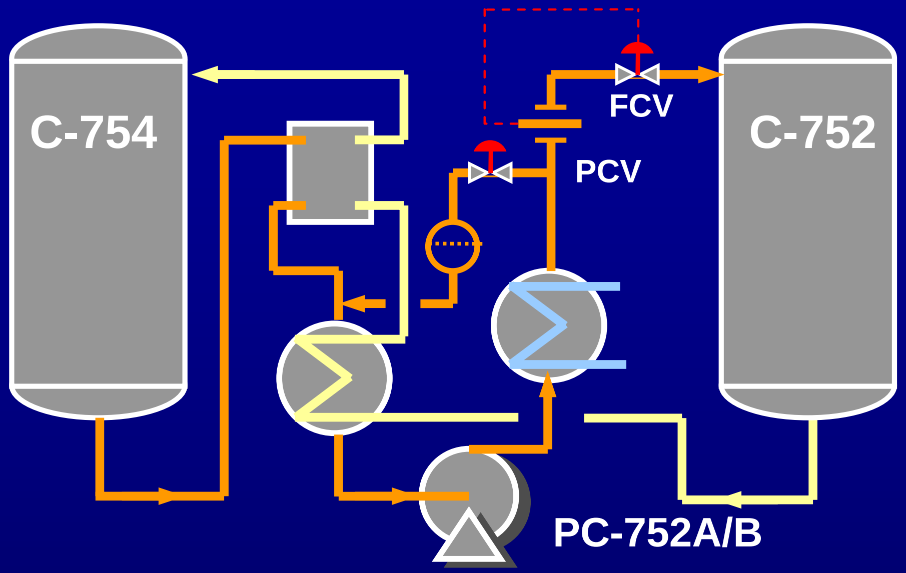
OBJECTIVE

A successful experience of reliability improvement of two process pumps, through the application of a cost-effective, "in-house" engineered component upgrade is presented.

The solution can be used as a reference to yield better mechanical performance of existing equipment in similar services.

SITUATION OVERVIEW



AMINE RECOVERY SERVICE

PUMP RATINGS:

Q : 262 m^3/hr (1,153 GPM)

H : 271 m (889 ft)

N : 3550 RPM

P : 290 kW (390 HP)

MAIN PUMP "A"

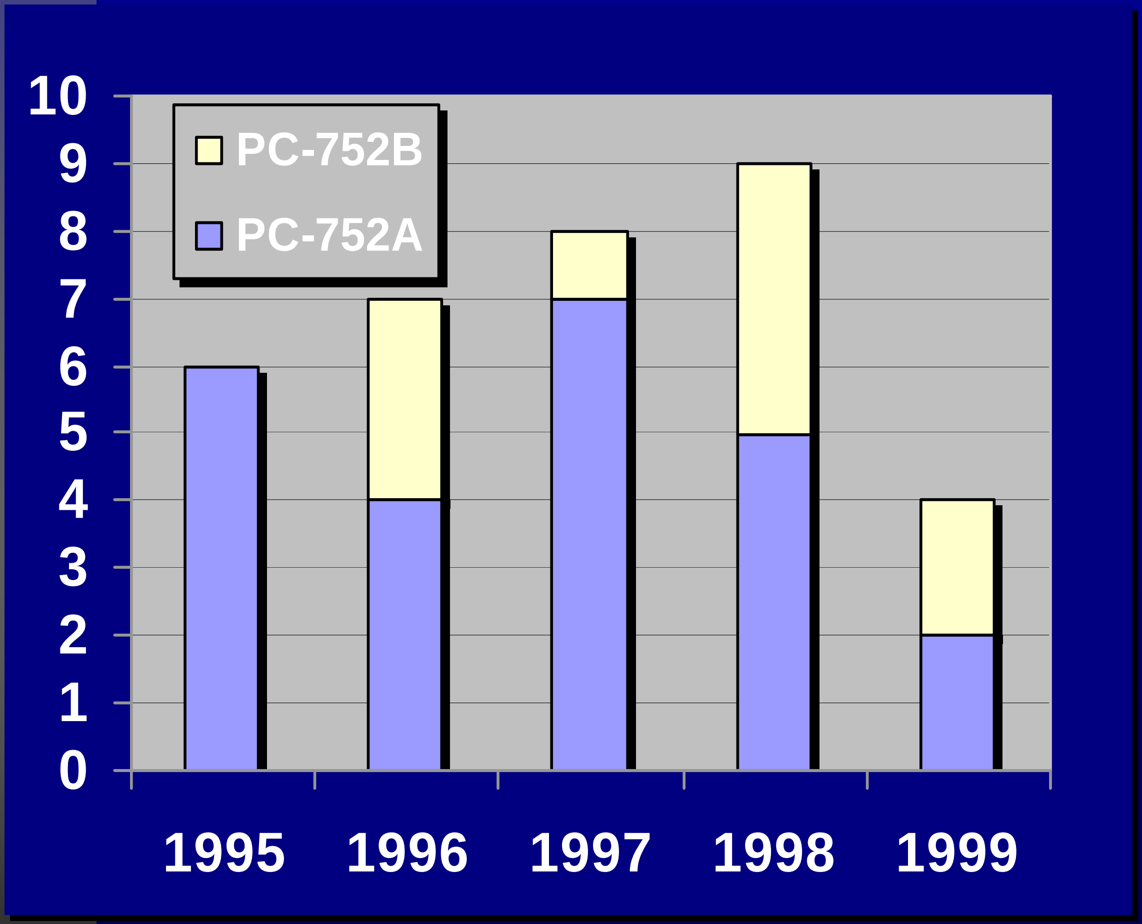
- **Turbine Driven**

STAND-BY PUMP "B"

- **Motor Driven**

PUMP FAILURES

EXPERIENCE OF CONTINUED LOW RELIABILITY



OPERATION PROBLEMS:

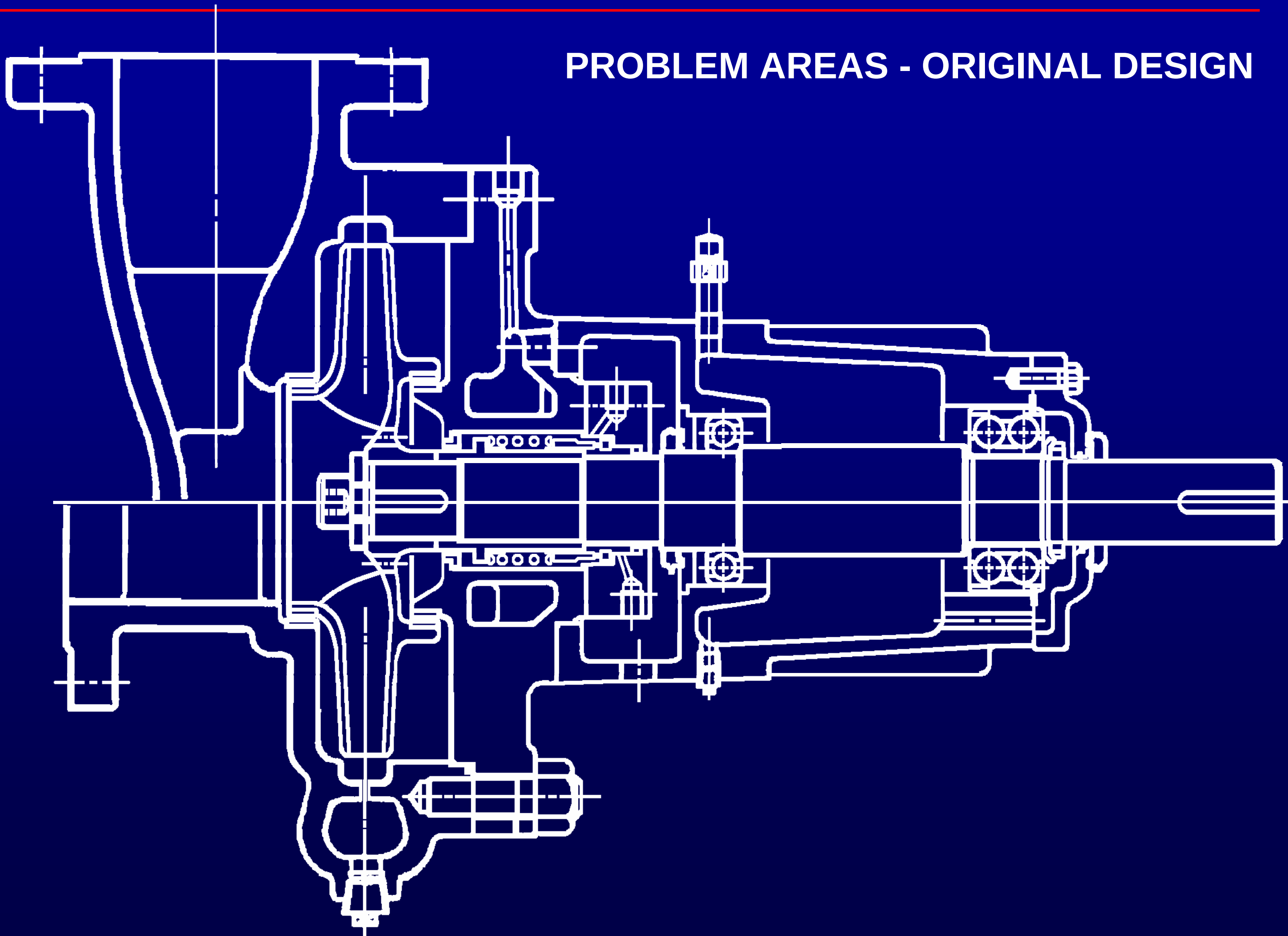
- **High Vibration**
- **Low Capacity**
- **Product Leakage**

FAILED COMPONENTS:

- **Impeller**
- **Wear Rings**
- **Shaft**
- **Bearings**
- **Mechanical Seal**

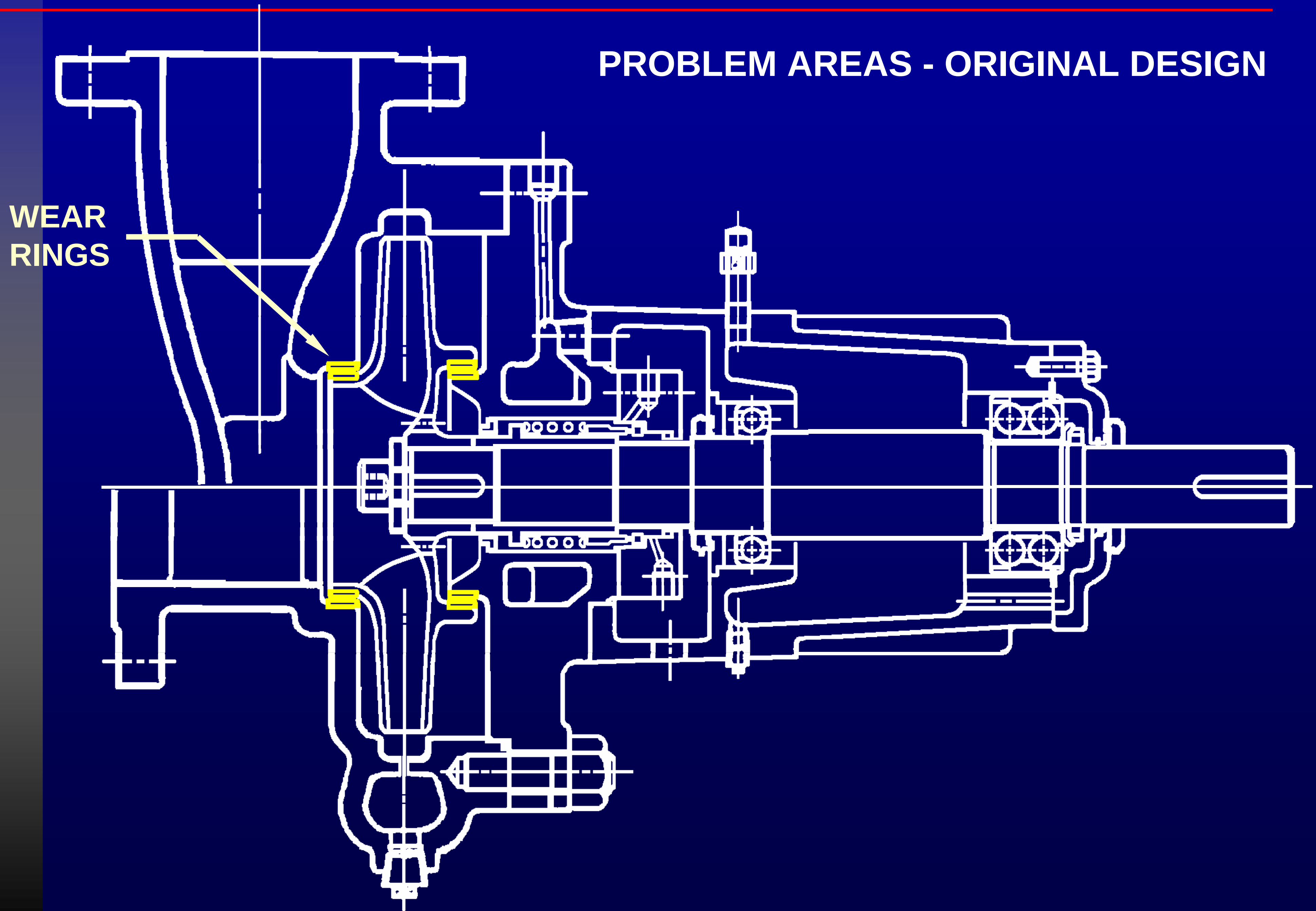
PUMP FAILURES

PROBLEM AREAS - ORIGINAL DESIGN



PUMP FAILURES

PROBLEM AREAS - ORIGINAL DESIGN



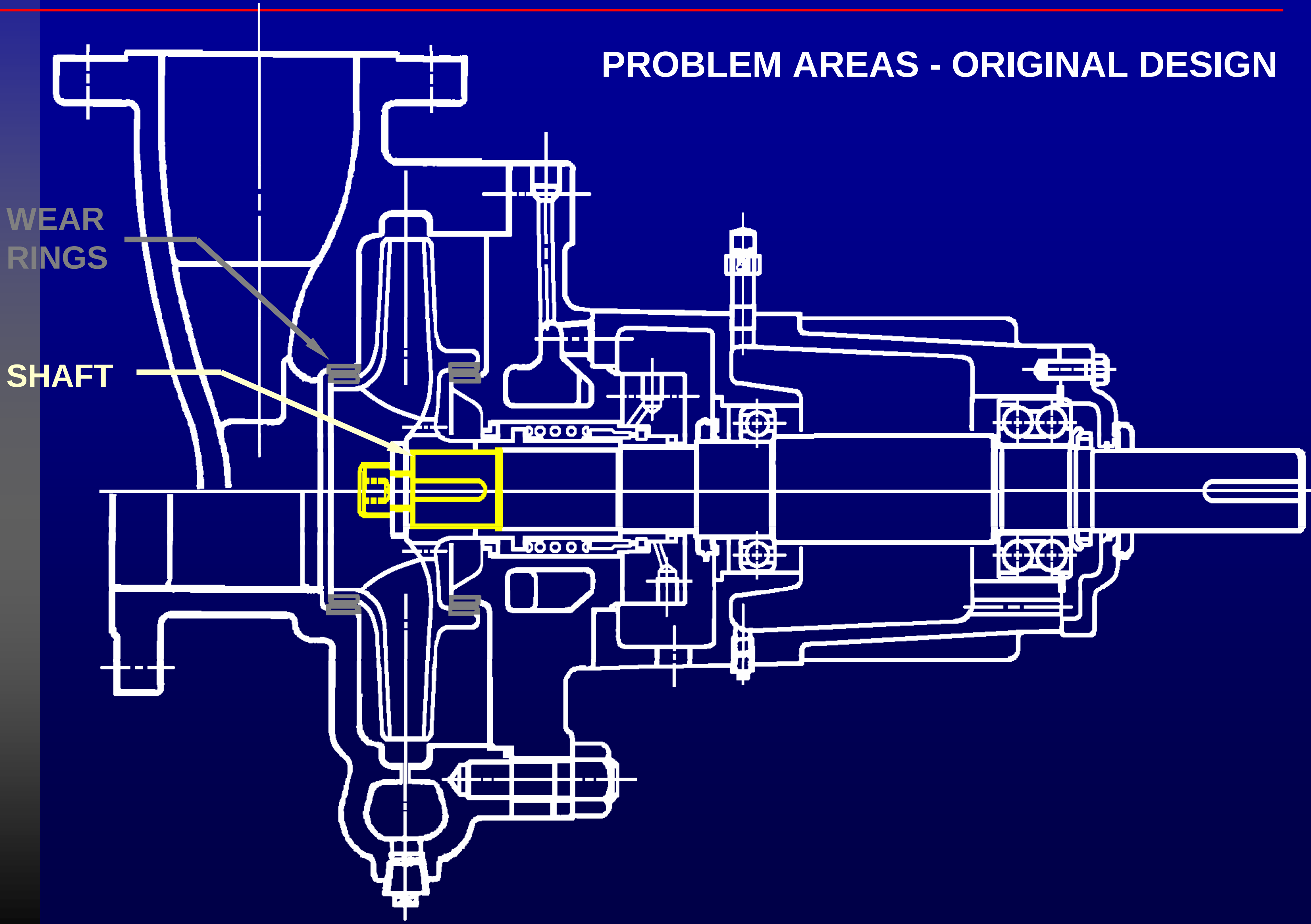
PUMP FAILURES

PROBLEM AREAS - ORIGINAL DESIGN

SEVERE RUBBING AT WEAR RINGS - 1996

PUMP FAILURES

PROBLEM AREAS - ORIGINAL DESIGN

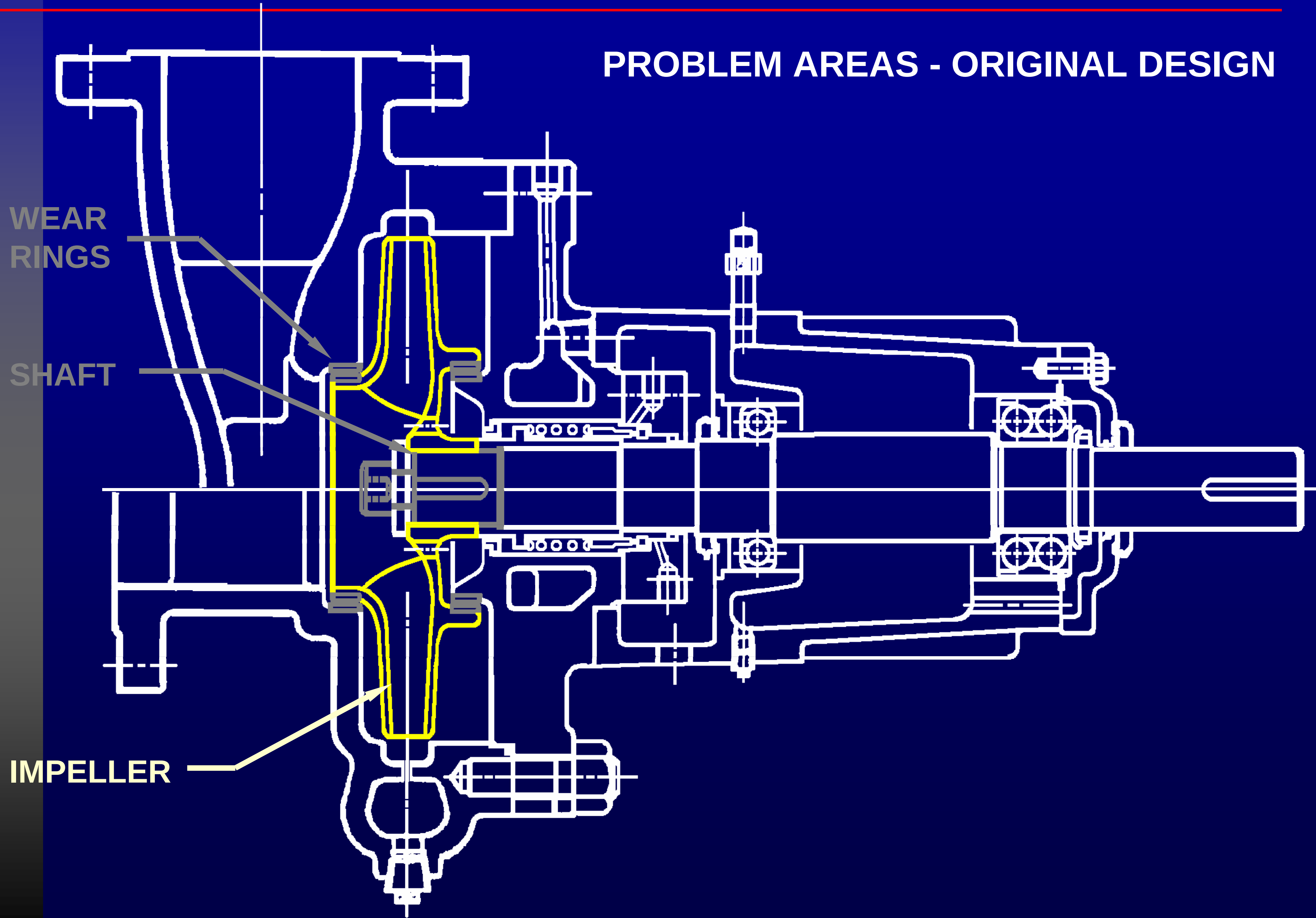


PUMP FAILURES

PROBLEM AREAS - ORIGINAL DESIGN

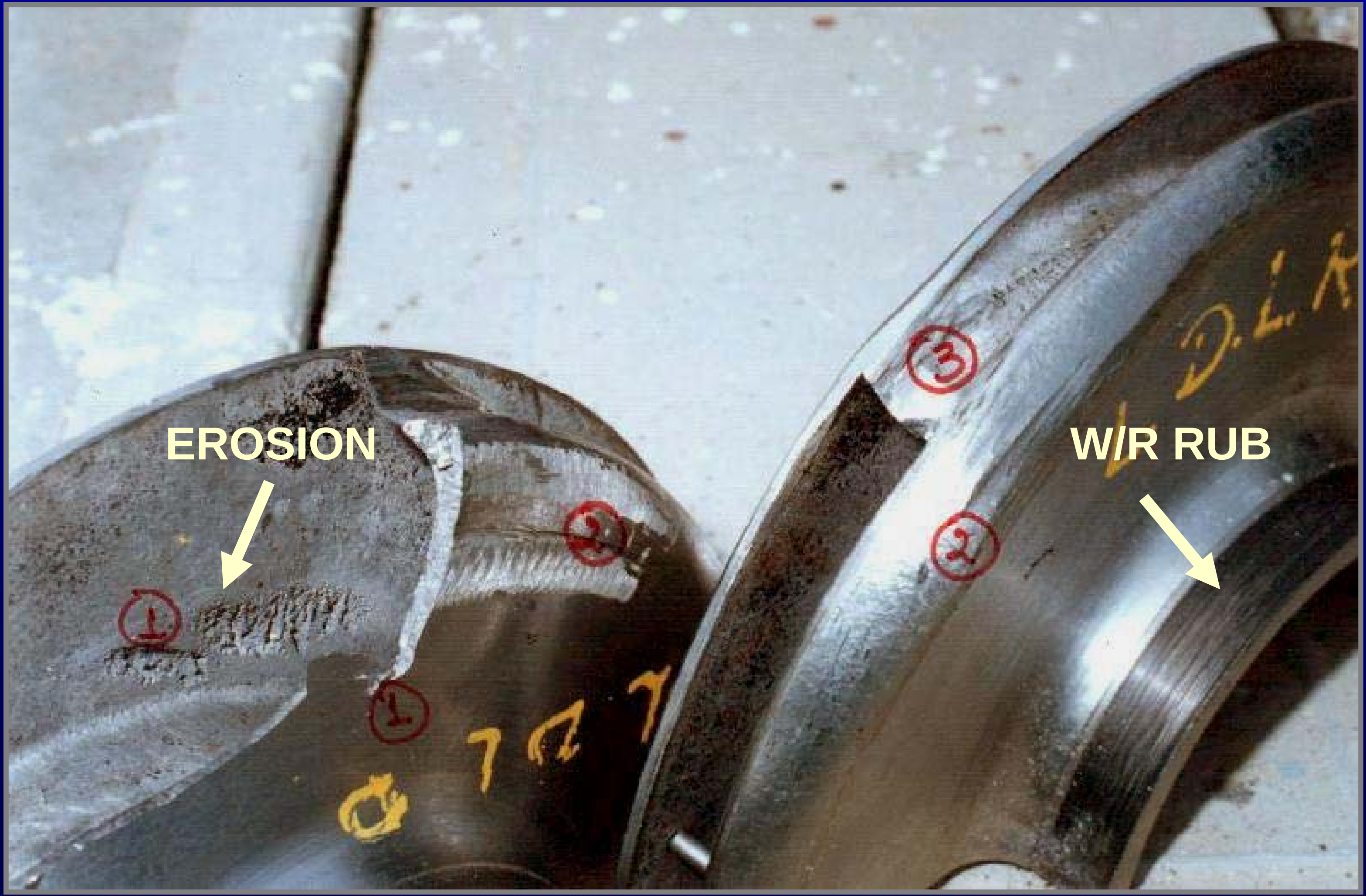
SHAFT FAILURE AT IMPELLER END - 1992

PUMP FAILURES



PUMP FAILURES

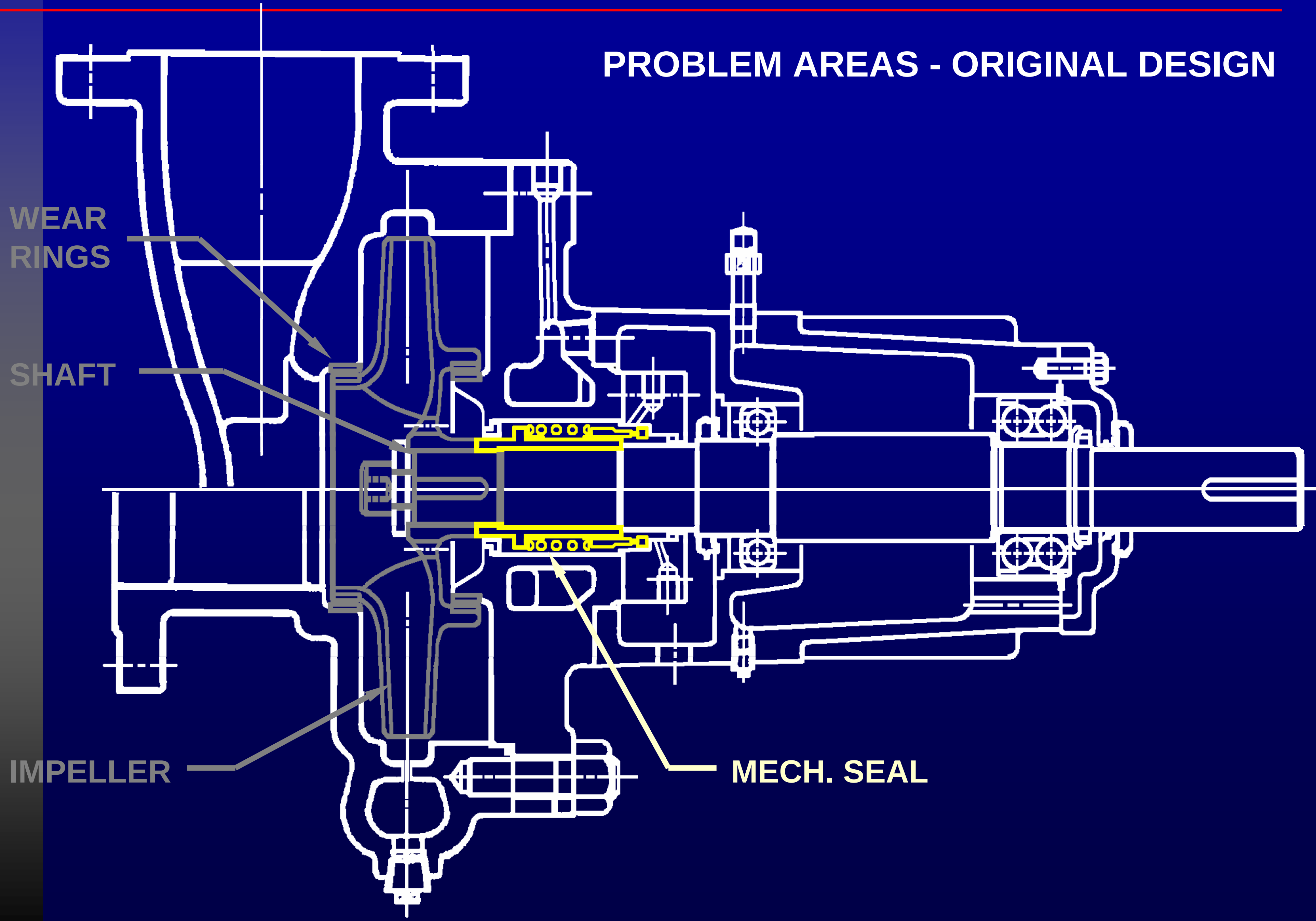
PROBLEM AREAS - ORIGINAL DESIGN



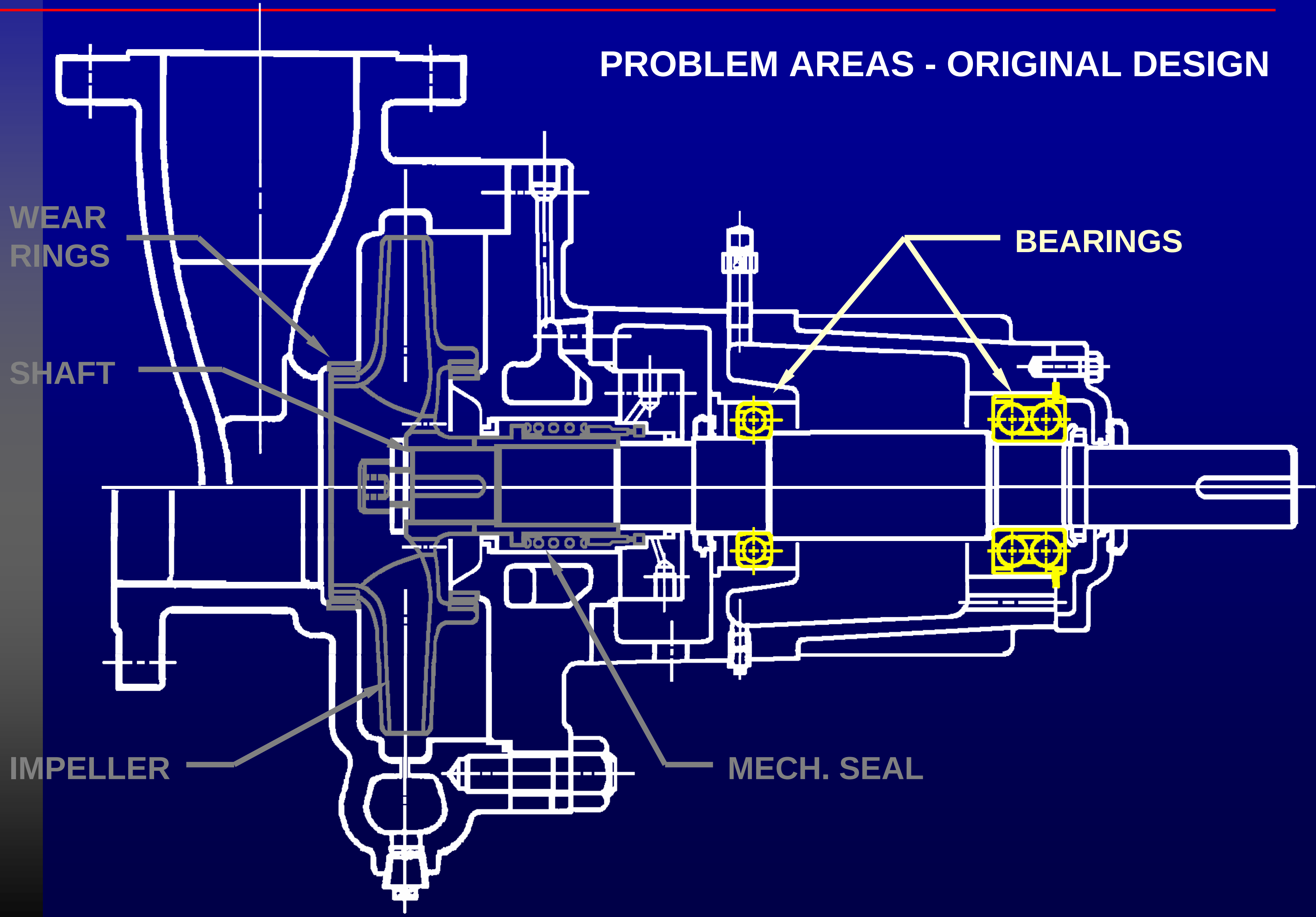
SEVERE IMPELLER FAILURE - 1992

PUMP FAILURES

PROBLEM AREAS - ORIGINAL DESIGN



PUMP FAILURES



PUMP FAILURES

REMEDIAL ACTIONS – HYSTORICAL REVIEW

YEAR	COMPONENT	ACTION
1980	Impeller	Installed pins between shrouds
1986	Shaft	Impeller capscrew replaced to fine thread
1991	Impeller	Local manufacture of impellers
1992	Shaft	Impeller capscrew replaced by a nut
1994	Wear Rings	Increase in wear ring clearances
1995	Impeller	Incorporation of 3 partial vanes
1996	Impeller	Impeller trim to pump “B”
1997	Impeller	Trimming of vanes at inlet
	Bearings	5313 thrust bearing replaced by 7313

PUMP FAILURES

REMEDIAL ACTIONS – HYSTORICAL REVIEW

YEAR	COMPONENT	DESCRIPTION
1980	Impeller	Installed pins between shrouds

PUMP FAILURES

REMEDIAL ACTIONS – HYSTORICAL REVIEW

1980

PINS INSTALLED BETWEEN IMPELLER SHROUDS

PUMP FAILURES

REMEDIAL ACTIONS – HYSTORICAL REVIEW

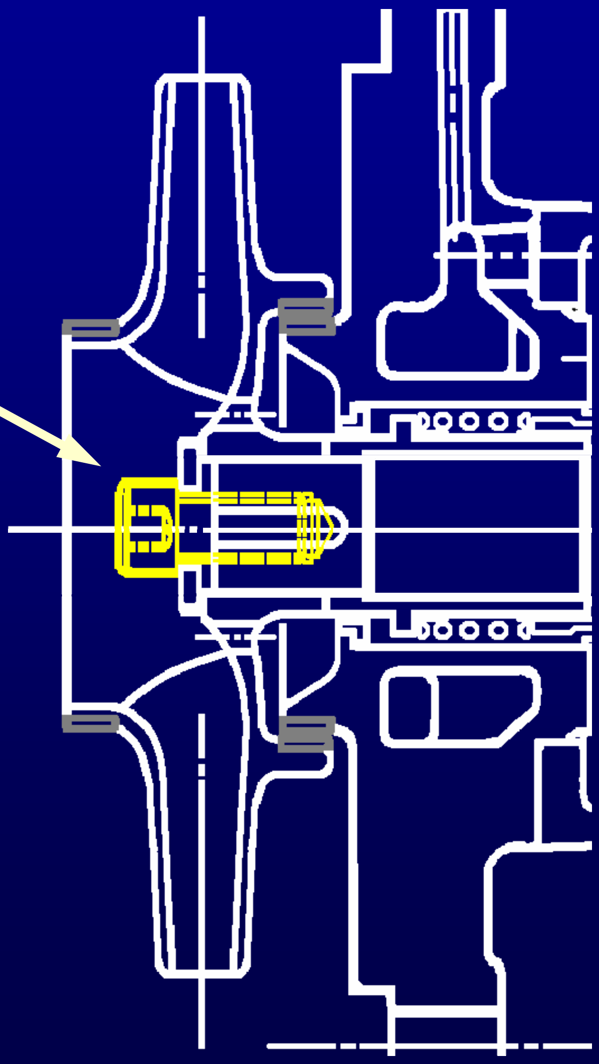
YEAR	COMPONENT	DESCRIPTION
1980	Impeller	Installed pins between shrouds
1986	Shaft	Impeller capscrew replaced to fine thread

PUMP FAILURES

REMEDIAL ACTIONS – HYSTORICAL REVIEW

1986

CAPSCREW M 24
NC TO NF



PUMP FAILURES

REMEDIAL ACTIONS – HYSTORICAL REVIEW

YEAR	COMPONENT	DESCRIPTION
1980	Impeller	Installed pins between shrouds
1986	Shaft	Impeller capscrew replaced to fine thread
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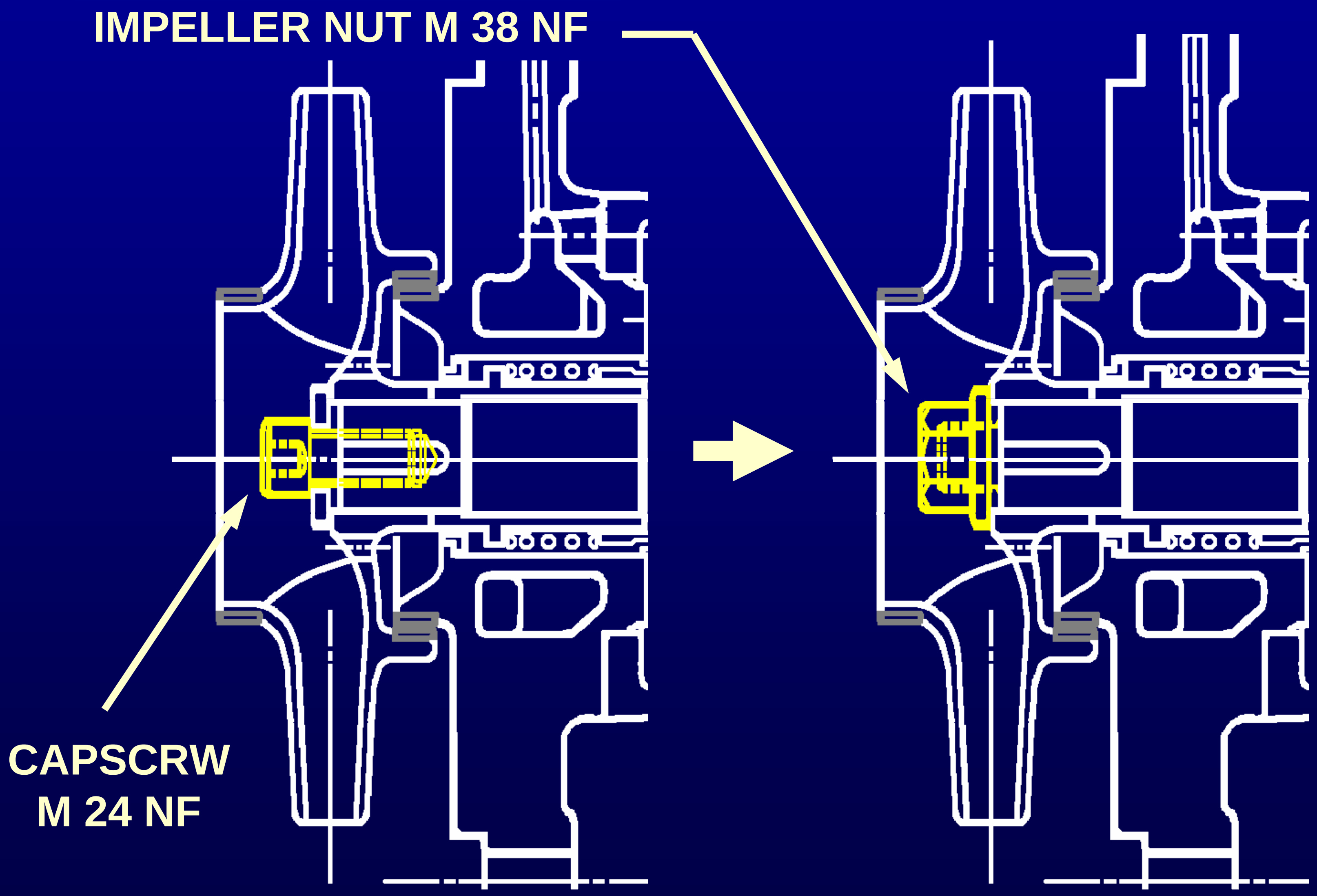
PUMP FAILURES

REMEDIAL ACTIONS – HYSTORICAL REVIEW

1992



PUMP FAILURES

REMEDIAL ACTIONS – HYSTORICAL REVIEW

Pump "B"

SHAFT FAILURE AT IMPELLER END - MAY 1999

PUMP FAILURES

REMEDIAL ACTIONS – HYSTORICAL REVIEW

YEAR	COMPONENT	DESCRIPTION
1980	Impeller	Installed pins between shrouds
1986	Shaft	Impeller capscrew replaced to fine thread
1991	Impeller	Local manufacture of impellers
1992	Shaft	Impeller capscrew replaced by a nut
1994	Wear Rings	Increase in wear rings running clearance
1995	Impeller	Incorporation of 3 partial vanes

PUMP FAILURES

REMEDIAL ACTIONS – HYSTORICAL REVIEW

1995

IMPELLER PATTERN WITH 3 PARTIAL VANES ADDED

EROSION CONTINUED

PUMP FAILURES

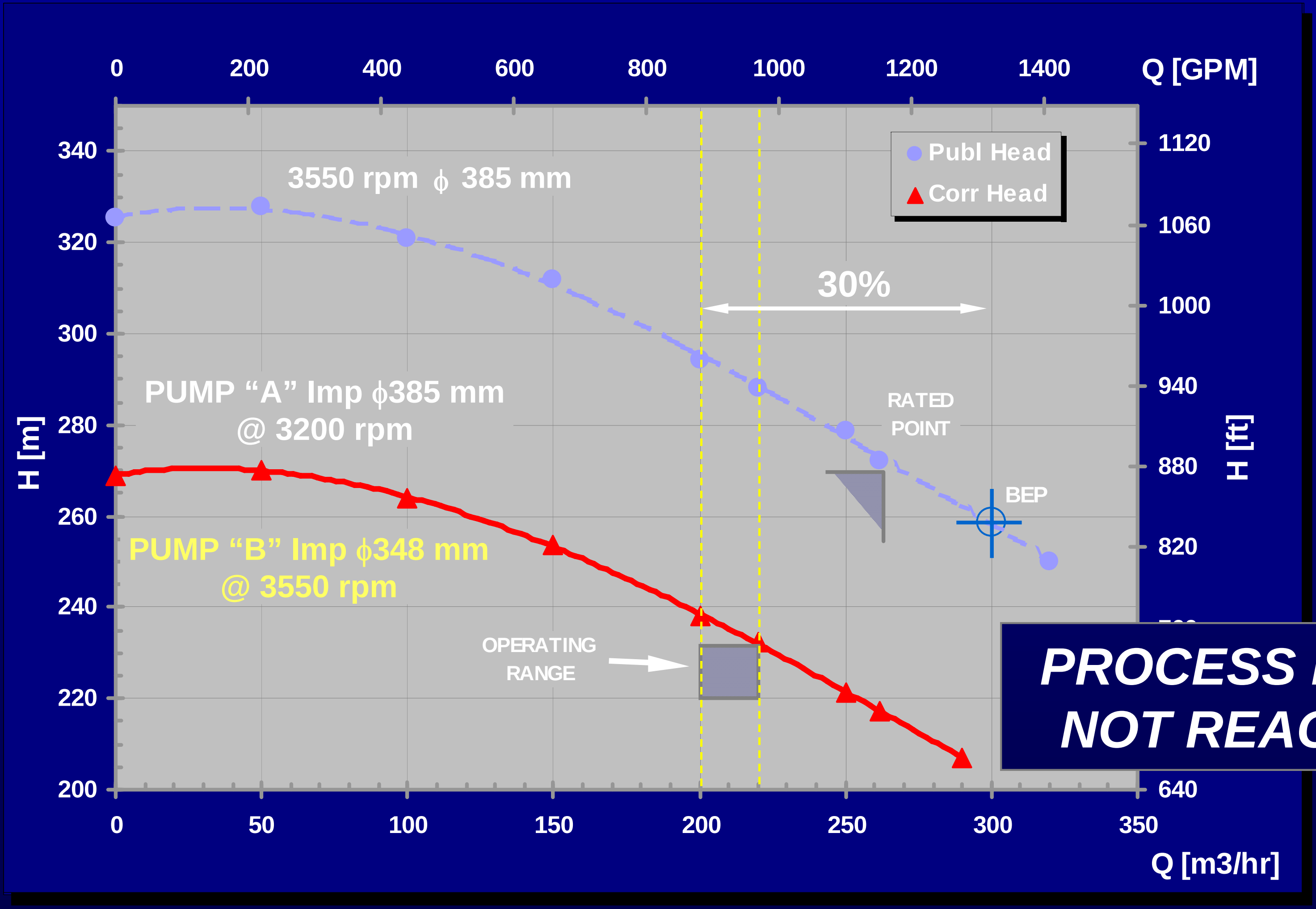
REMEDIAL ACTIONS – HYSTORICAL REVIEW

YEAR	COMPONENT	DESCRIPTION
1980	Impeller	Installed pins between shrouds
1986	Shaft	Impeller capscrew replaced to fine thread
1991	Impeller	Local manufacture of impellers
1992	Shaft	Impeller capscrew replaced by a nut
1994	Wear Rings	Increase in wear rings running clearance
1995	Impeller	Incorporation of 3 partial vanes
1996	**Impeller**	**Impeller trim to pump “B”**

PUMP FAILURES

REMEDIAL ACTIONS – HYSTORICAL REVIEW

1996



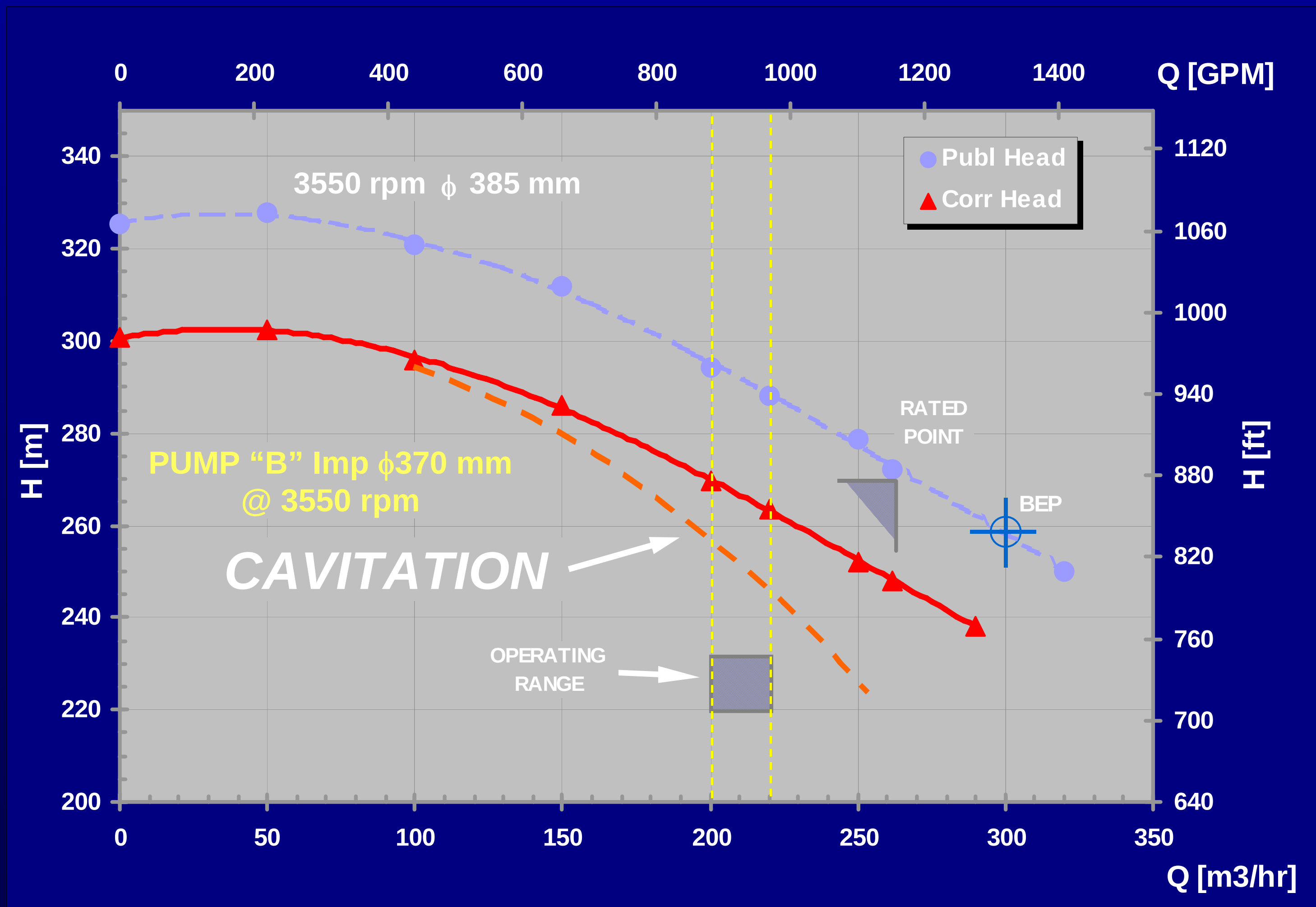
PROCESS FLOW NOT REACHED

IMPELLER TRIM OF STAND-BY PUMP “B”

PUMP FAILURES

REMEDIAL ACTIONS – HYSTORICAL REVIEW

1996



IMPELLER TRIM OF STAND-BY PUMP "B"

PUMP FAILURES

REMEDIAL ACTIONS – HYSTORICAL REVIEW

YEAR	COMPONENT	DESCRIPTION
1980	Impeller	Installed pins between shrouds
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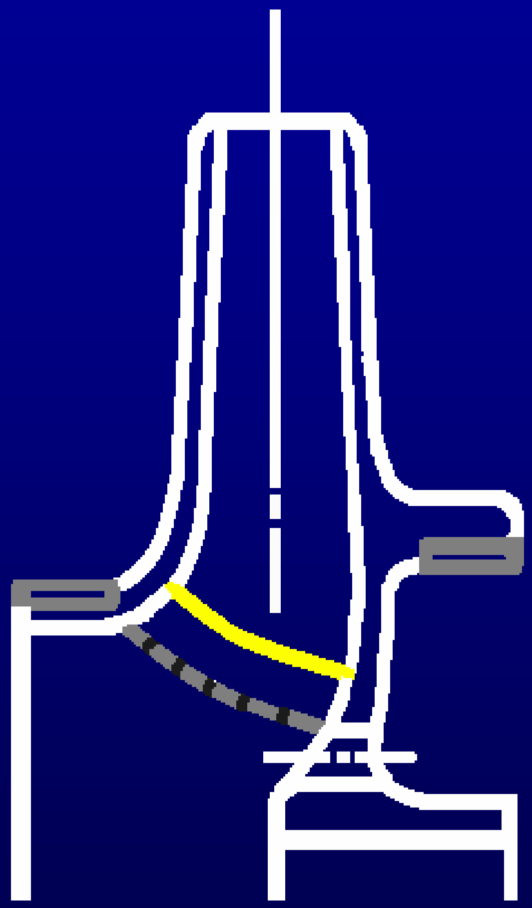
1997	**Impeller**	**Trimming of vanes at inlet**

PUMP FAILURES

REMEDIAL ACTIONS – HYSTORICAL REVIEW

1997



VANE TRIM AT IMPELLER INLET TO REDUCE NPSHR

IMPROPERLY EFFECTED

PUMP FAILURES

REMEDIAL ACTIONS – HYSTORICAL REVIEW

YEAR	COMPONENT	DESCRIPTION
1980	Impeller	Installed pins between shrouds
1986	Shaft	Impeller capscrew replaced to fine thread
1991	Impeller	Local manufacture of impellers
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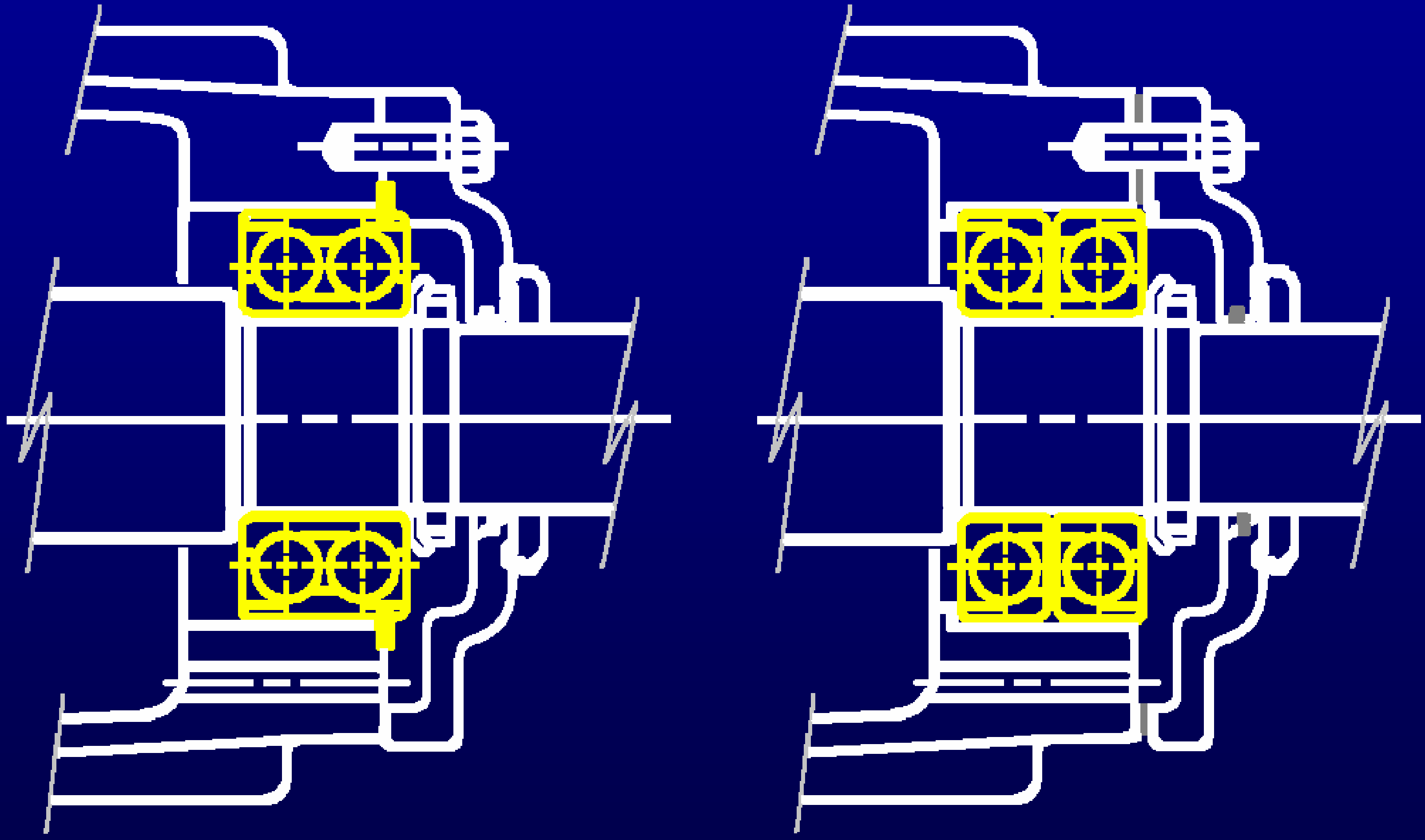
	Bearings	5313 thrust bearing replaced by 7313 BG

PUMP FAILURES

REMEDIAL ACTIONS – HYSTORICAL REVIEW

1997



THRUST BEARING UPGRADE FROM 3313 TO 7313 BG

PUMP FAILURES

CATASTROPHIC FAILURE – PUMP "B"

SEPT 1998

PRELIMINARY ANALYSIS

RECURRENT PUMP FAILURES
SEPT 1999

- **Unsuccessful efforts to improve reliability.**
- **Solutions mainly focused in the consequences rather than the causes for the problems.**
- **Improper procedures contribute to failures.**
- **Complex problem with multiple correlated causes and failure modes.**
- **Global solution required.**

PROBLEM ANALYSIS

FACTORS ASSOCIATED TO LOW RELIABILTY

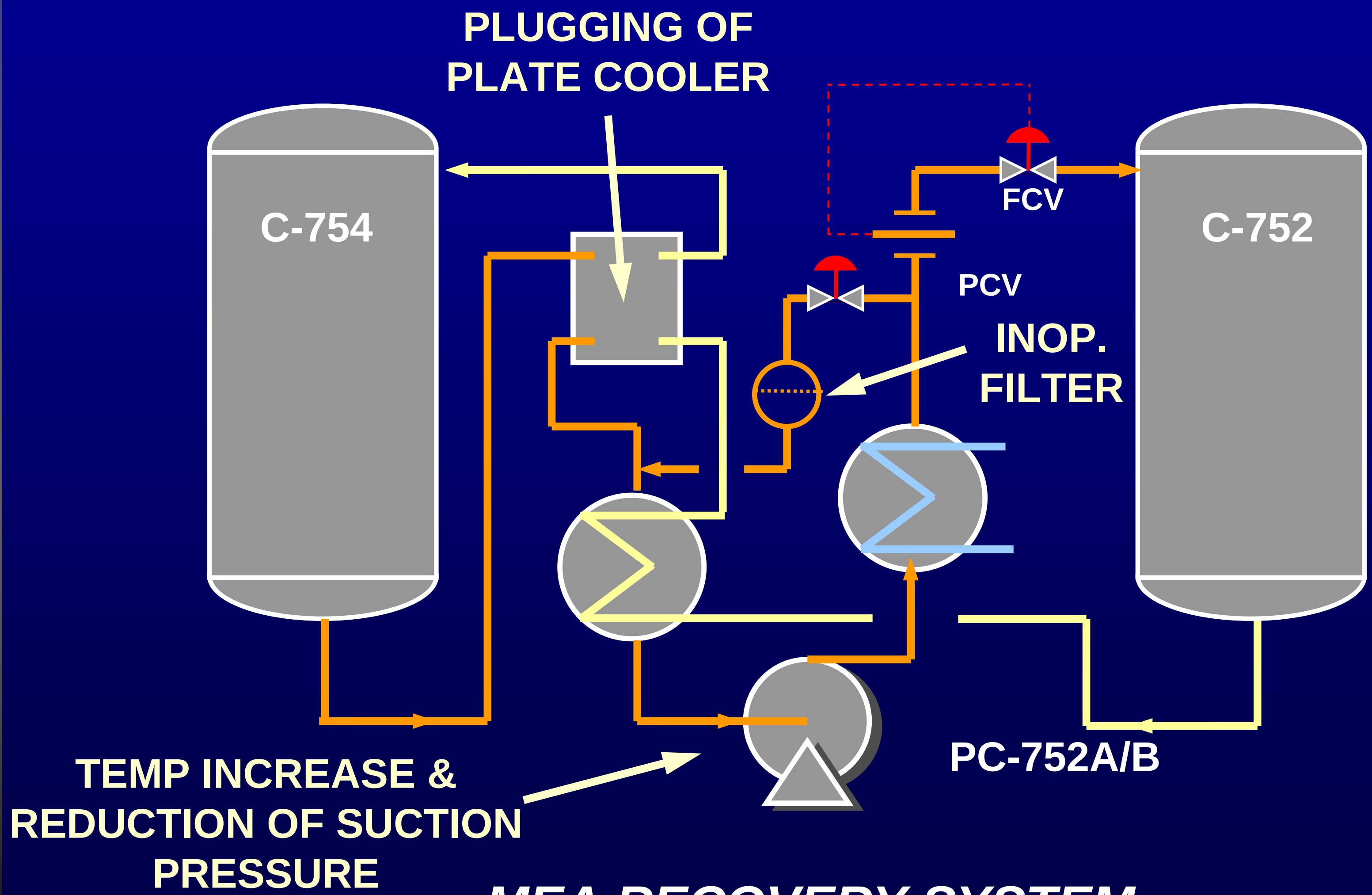
SEPT 1999

- ***OPERATIONAL***
  - **Low NPSHA**

PROBLEM ANALYSIS

FACTORS ASSOCIATED TO LOW RELIABILTY

SUCTION CONDITIONS - 1999



MEA RECOVERY SYSTEM

PROBLEM ANALYSIS

FACTORS ASSOCIATED TO LOW RELIABILTY

SUCTION CONDITIONS - 1999

		DESIGN	REVISED 1997	MEASURED
Fluid		20% MEA	30% MEA	30% MEA
Temp	[ºC]	92	95 – 99	99
SG		0.965	1.015	
VP	[kg/cm^2 a]	0.78	1.05	
Suct. Press.	[kg/cm^2 g]	0.60	0.50	0.25 – 0.60
Flow	[m^3/hr]	228 – 262	200 – 220	200 – 220
NPSH A	[m]	9.00	4.90	2.45 – 5.90
NPSH R	[m]	6.50	4.00 ?	4.00 ?
NPSH MARGIN		38%	INSUFFICIENT	NONE

PROBLEM ANALYSIS

FACTORS ASSOCIATED TO LOW RELIABILTY

SUCTION CONDITIONS - 1999

		DESIGN	REVISED 1997	MEASURED
Fluid		20% MEA	30% MEA	30% MEA
Temp	[F]	198	203 – 210	210
SG		0.965	1.015	
VP	[psia]	11.1	14.9	
Suct. Press.	[psia]	8.5	7.1	3.5 – 8.5
Flow	[GPM]	1000 – 1153	880 – 970	880 – 970
NPSH A	[ft]	29.5	16.0	8.0 – 19.3
NPSH R	[ft]	21.3	13.1 ?	13.1 ?
NPSH MARGIN		38%	INSUFFICIENT	NONE

PROBLEM ANALYSIS

FACTORS ASSOCIATED TO LOW RELIABILTY

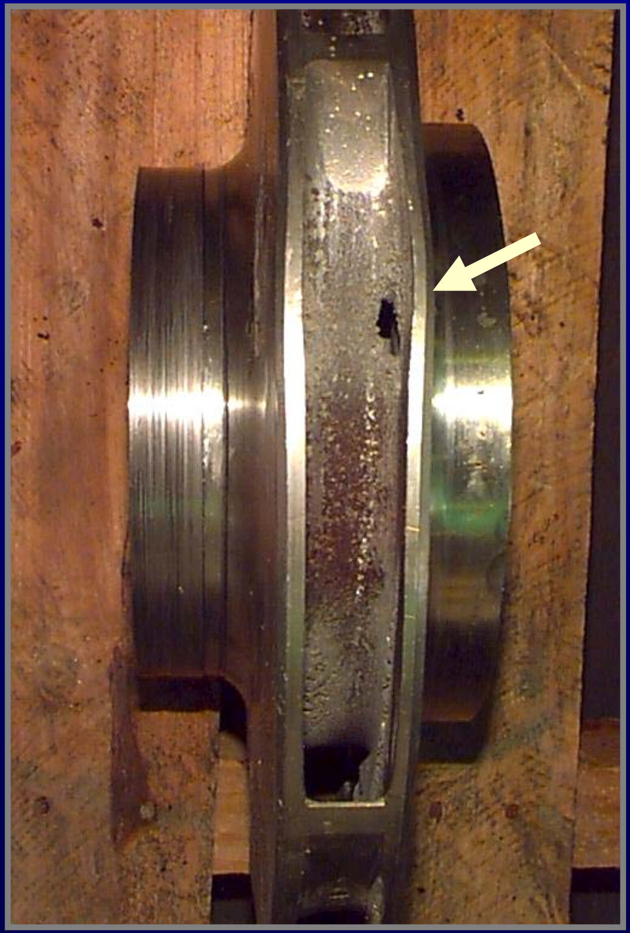
SEPT 1999

- ***OPERATIONAL***
  - **Low NPSHA**
  - **Part load operation**

PROBLEM ANALYSIS

FACTORS ASSOCIATED TO LOW RELIABILTY

PART LOAD OPERATION - 1999



EROSION & SHROUD SEPARATION

EVIDENCES OF RECIRCULATION AT DISCHARGE

PROBLEM ANALYSIS

FACTORS ASSOCIATED TO LOW RELIABILTY

SEPT 1999

- ***OPERATIONAL***
  - **Low NPSHA**
  - **Part load operation**
  - **Process disturbances (flow/pressure surges)**

MAY CONTINUE

- ***MAINTENANCE***
  - **Inoperative pipe supports**
    - **Transmission of pipe forces**
    - **Excessive deflection**

PROBLEM ANALYSIS

FACTORS ASSOCIATED TO LOW RELIABILTY

MAINTENANCE PROBLEMS - 1999

INOPERATIVE PIPE SUPPORTS

PROBLEM ANALYSIS

FACTORS ASSOCIATED TO LOW RELIABILTY

SEPT 1999

- ***OPERATIONAL***
  - **Low NPSHA**
  - **Part load operation**
  - **Process disturbances (flow/pressure surges)**

MAY CONTINUE

- ***MAINTENANCE***
  - **Inoperative pipe supports**
    - **Transmission of pipe forces**
    - **Excessive deflection**
  - **Improper procedures**

EASILY CORRECTED

PROBLEM ANALYSIS

FACTORS ASSOCIATED TO LOW RELIABILTY

SEPT 1999

- ***MANUFACTURING DEFICIENCIES***
  - **Shaft (own shop)**
  - **Impeller (local mfr)**
- ***DESIGN WEAKNESSES***
  - **Dated 1969**
  - **Hydraulics**
  - **Component Stiffness**
  - **Choice of Materials**

PUMP UPGRADE

PROBLEM ANALYSIS

CORRELATION OF CAUSES FOR LOW RELIABILITY

MAIN CAUSES	IMMEDIATE EFFECTS	CONSEQUENCES	NOTICEABLE EFFECTS	EXPECTED FAILURE
OPERATION • Plugged Filters / Coolers • Too low NPSHA • Part load operation • Process disturbances ***MAINTENANCE*** • Inoperative pipe supports • Improper wear ring materials • Improper vane trim at inlet ***MANUFACTURE*** • Improper part. vane position • Insufficient shaft fillet radii ***DESIGN*** • Deficiencies in hydraulics • Insufficient stiffness • Inadequate shaft end design • Choice of materials	• CAVITATION • INTERNAL RECIRCULATION • TURBULENCE • VIBRATION • INCREASE OF NPSHR • PIPE FORCES • STRESS RISERS • INSUFFICIENT MAT PROPERTIES • MAT OF SIMILAR GALLING TENDENCY	• IMPELLER EROSION • IMBALANCE • LARGE LOADS • LARGE STRESSES • LARGE DEFLECTIONS • SEVERE RUBS • LOSS OF RUNNING CLEARANCES • SHAFT FATIGUE • LOSS OF FUNCTION	• VIBRATION INCREASE • NOISE • LOSS OF CAPACITY • SEAL LEAKAGE	• IMPELLER • WEAR RINGS • SHAFT • BEARINGS • MECH. SEAL

PUMP UPGRADE

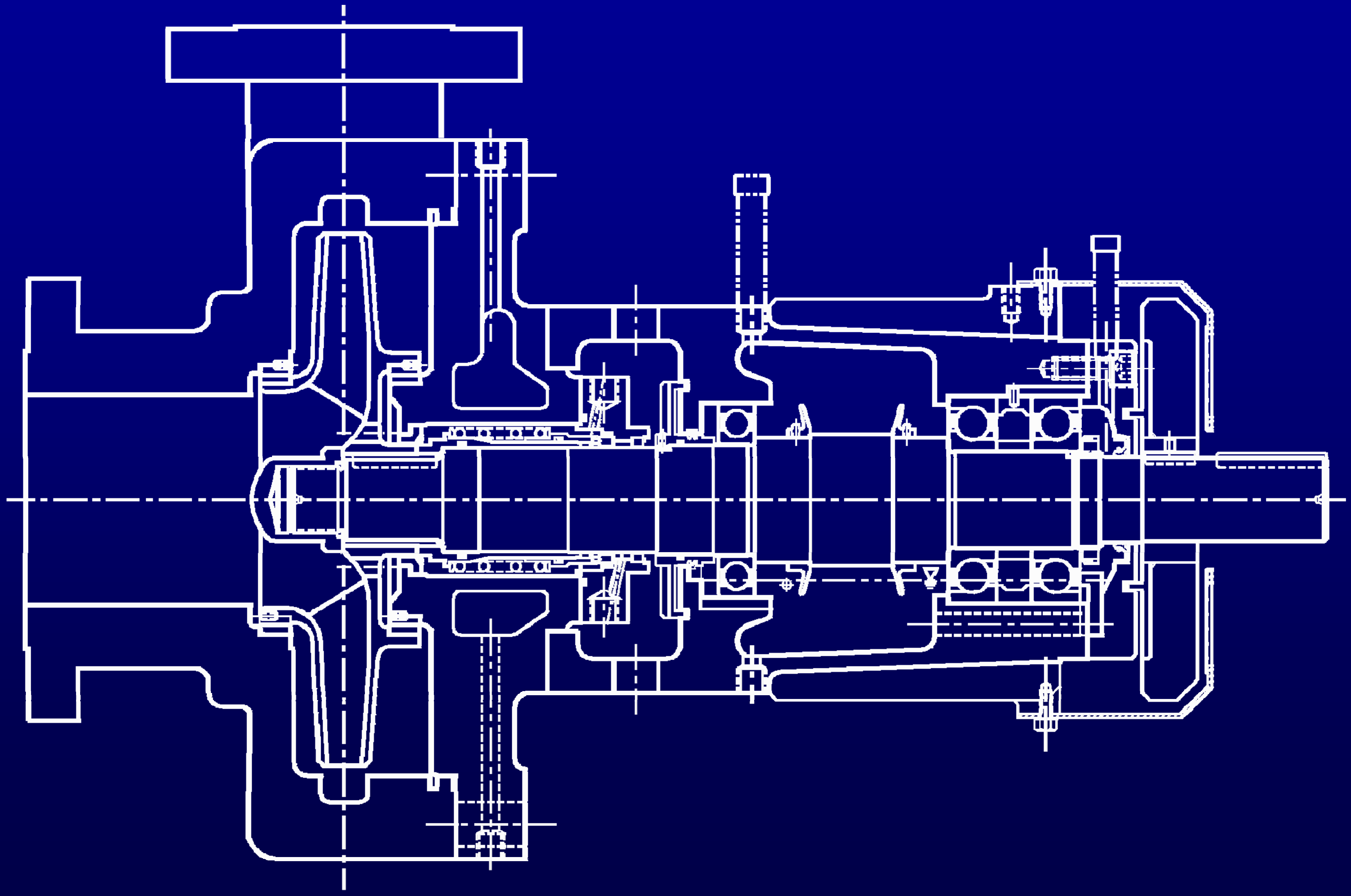
IMPLEMENTATION OF SOLUTIONS

OBJECTIVES:

- **Identify & solve design weaknesses.**
- **Correct component manufacturing deficiencies.**
- **Incorporate modifications for improved reliability.**
- **Withstand tough operating conditions with low NPSHA.**
- **Manufacture of new parts, pump refurbishment, stand testing & performance adjustment to requirements by a qualified supplier.**

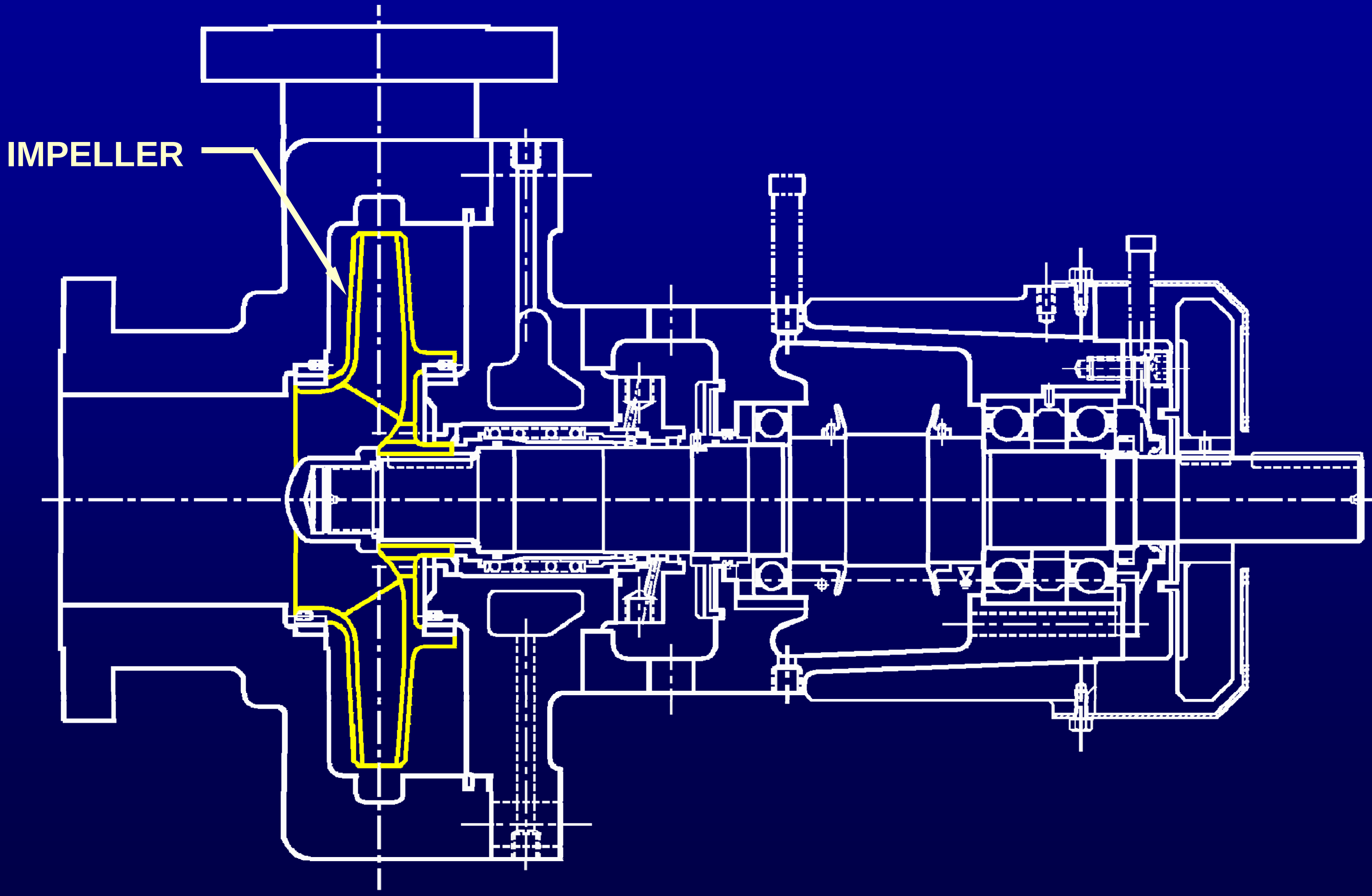
PUMP UPGRADE

AREAS OF ATTENTION



PUMP UPGRADE

AREAS OF ATTENTION



PUMP UPGRADE

IMPELLER IMPROVEMENT

BEFORE

AFTER

VANE CORRECTIONS

PUMP UPGRADE

IMPELLER IMPROVEMENT

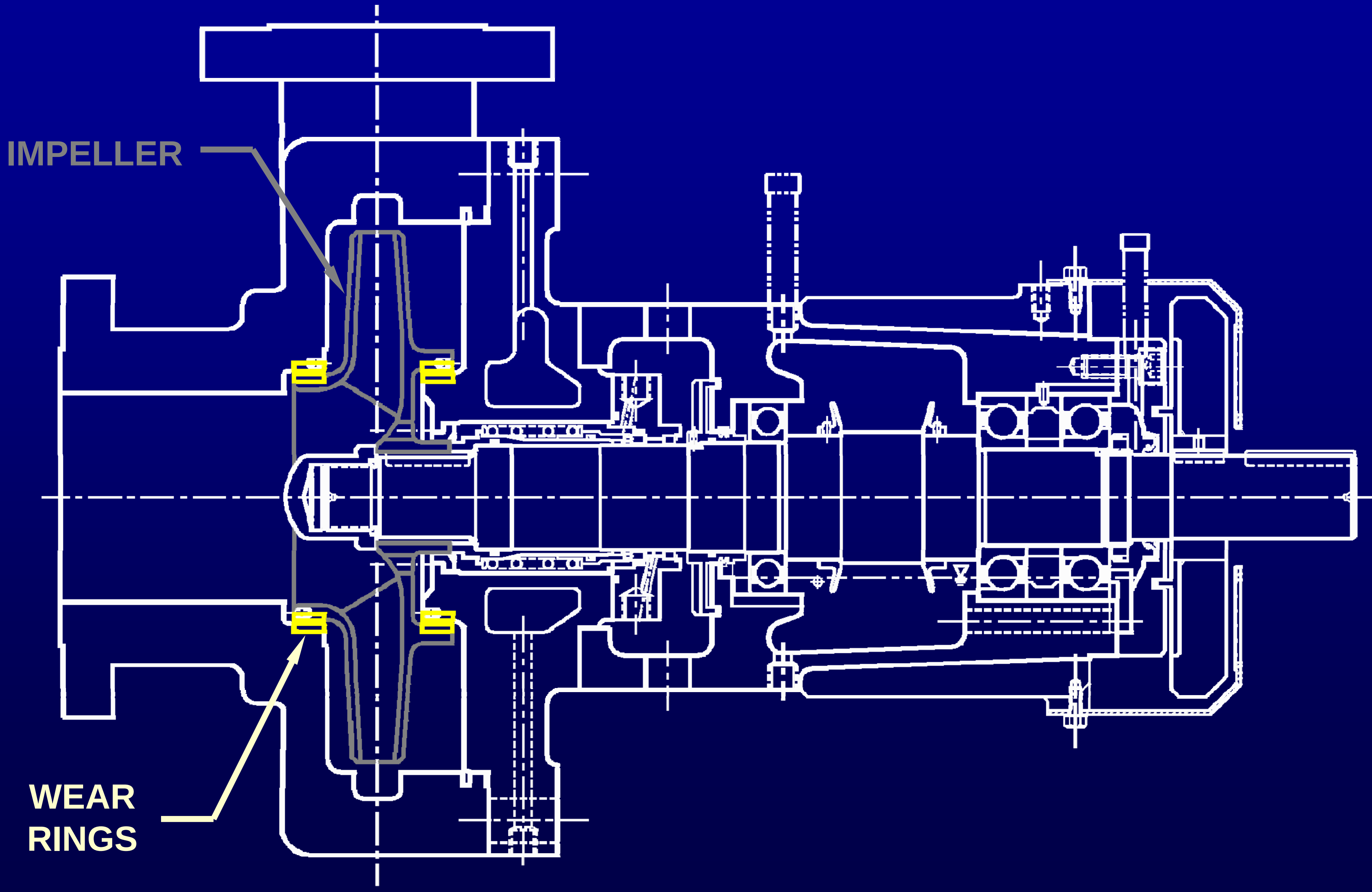
MANUFACTURING MATERIAL:

ORIGINAL	NEW
AISI 304	18Cr-16Mn

VANE LEADING EDGE / MATERIAL IMPROVEMENT

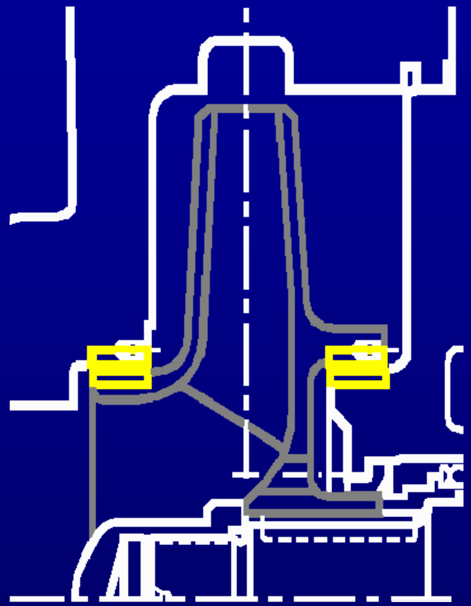
PUMP UPGRADE

AREAS OF ATTENTION



PUMP UPGRADE

WEAR RINGS IMPROVEMENT



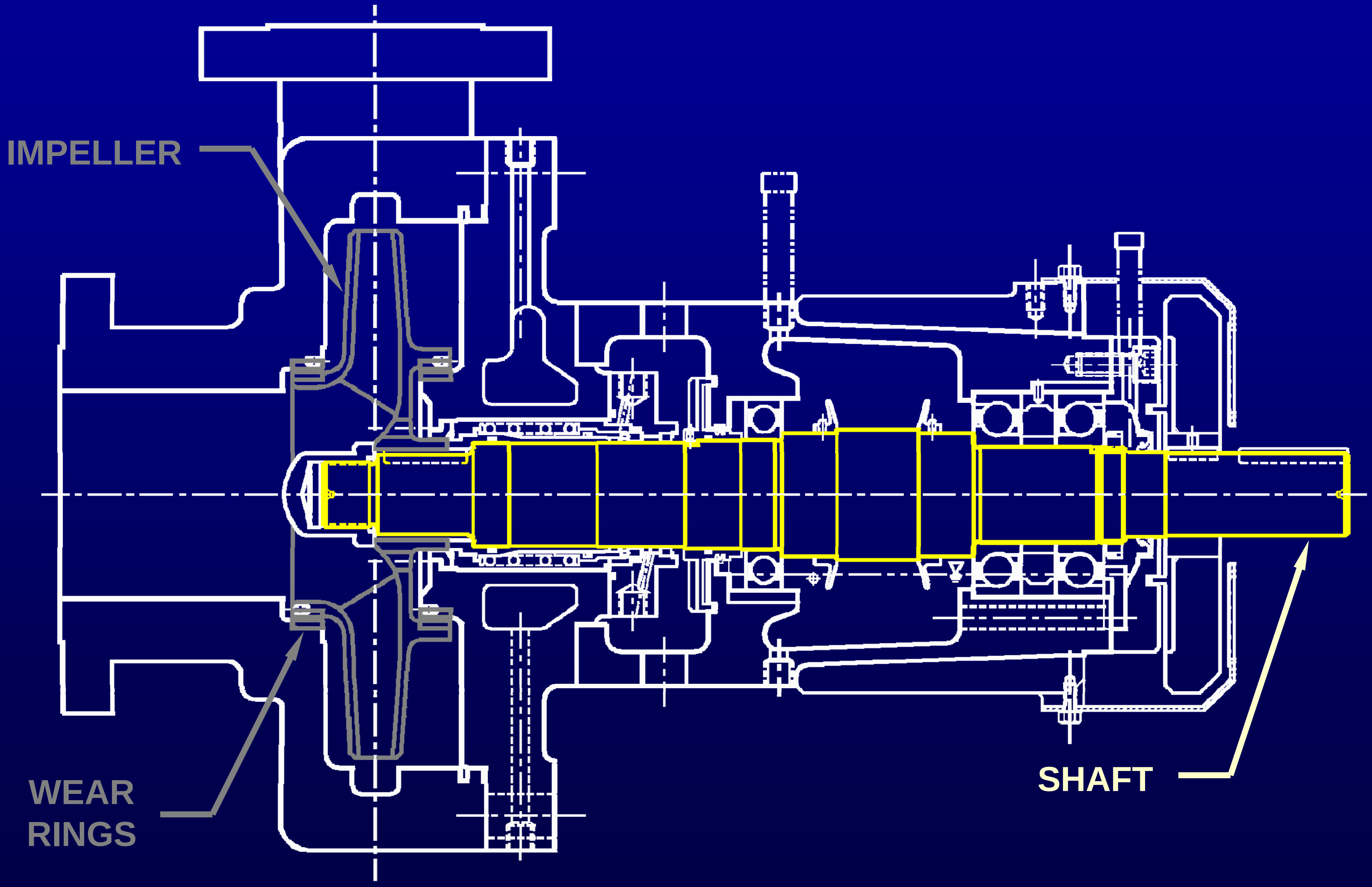
MANUFACTURING MATERIALS:

	DESIGN	IN USE (1999)	NEW	
			ALT 1	ALT 2
IMPELLER	AISI 304 Stellitted	AISI 304	AISI 304 + Cr. Plating	18Cr-16Mn
CASING	AISI 304	AISI 304	18Cr-16Mn	AISI 304

WEAR RINGS MATERIALS

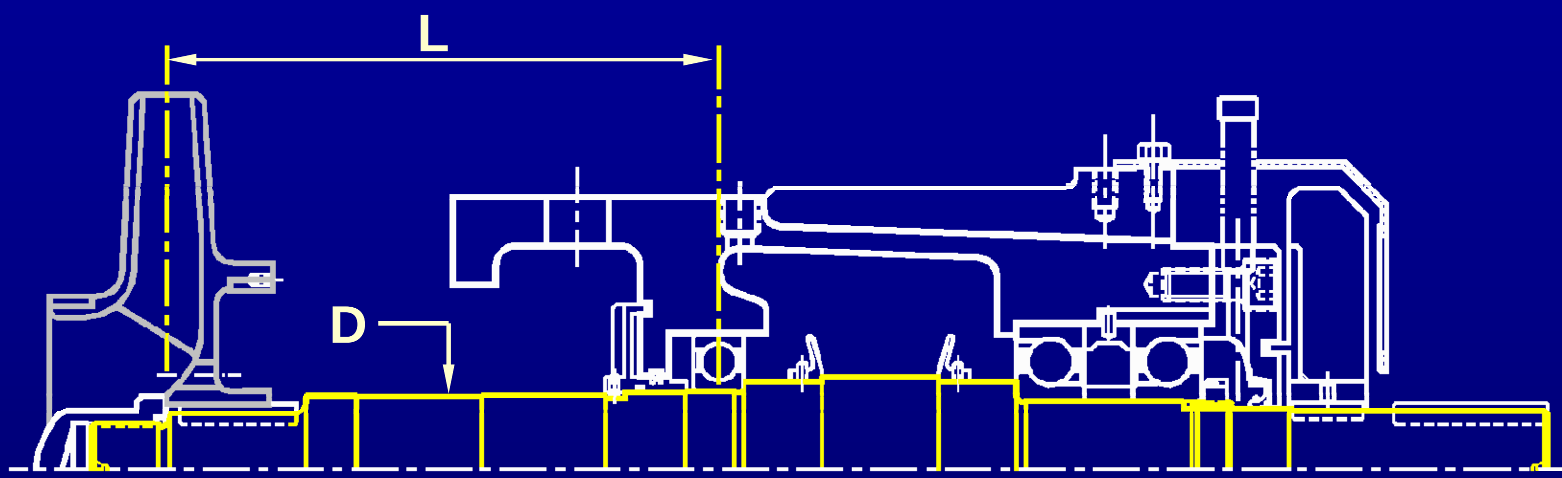
PUMP UPGRADE

AREAS OF ATTENTION



PUMP UPGRADE

SHAFT IMPROVEMENT

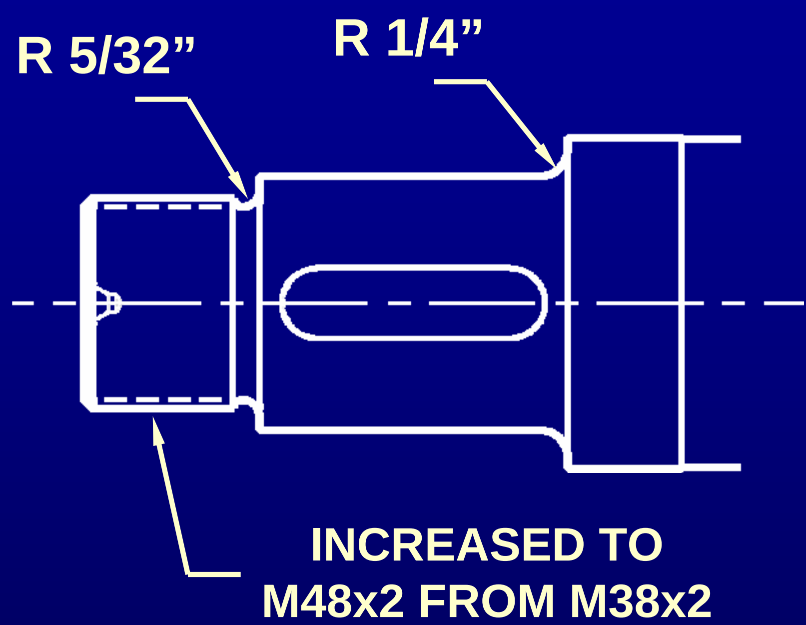


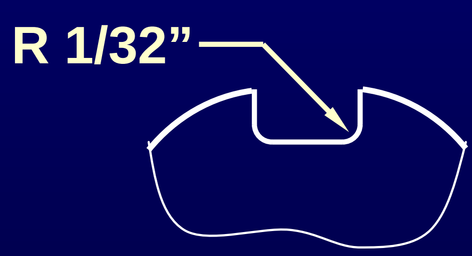
API 610 Ed.	DESIGN (1969)	SAME MFR 7th	MFR 2 8th	MFR 3 8th	APPLIED
L [in]	10.91	12.25	11.25	11.50	11.18
D [in]	2.480	2.937	2.625	2.440	2.953
L^3 / D^4	34.3	24.7	30	43	18.4
Improvement	–	39%	14%	– 20%	86%

SHAFT FLEXIBILITY COMPARISON

PUMP UPGRADE

SHAFT IMPROVEMENT





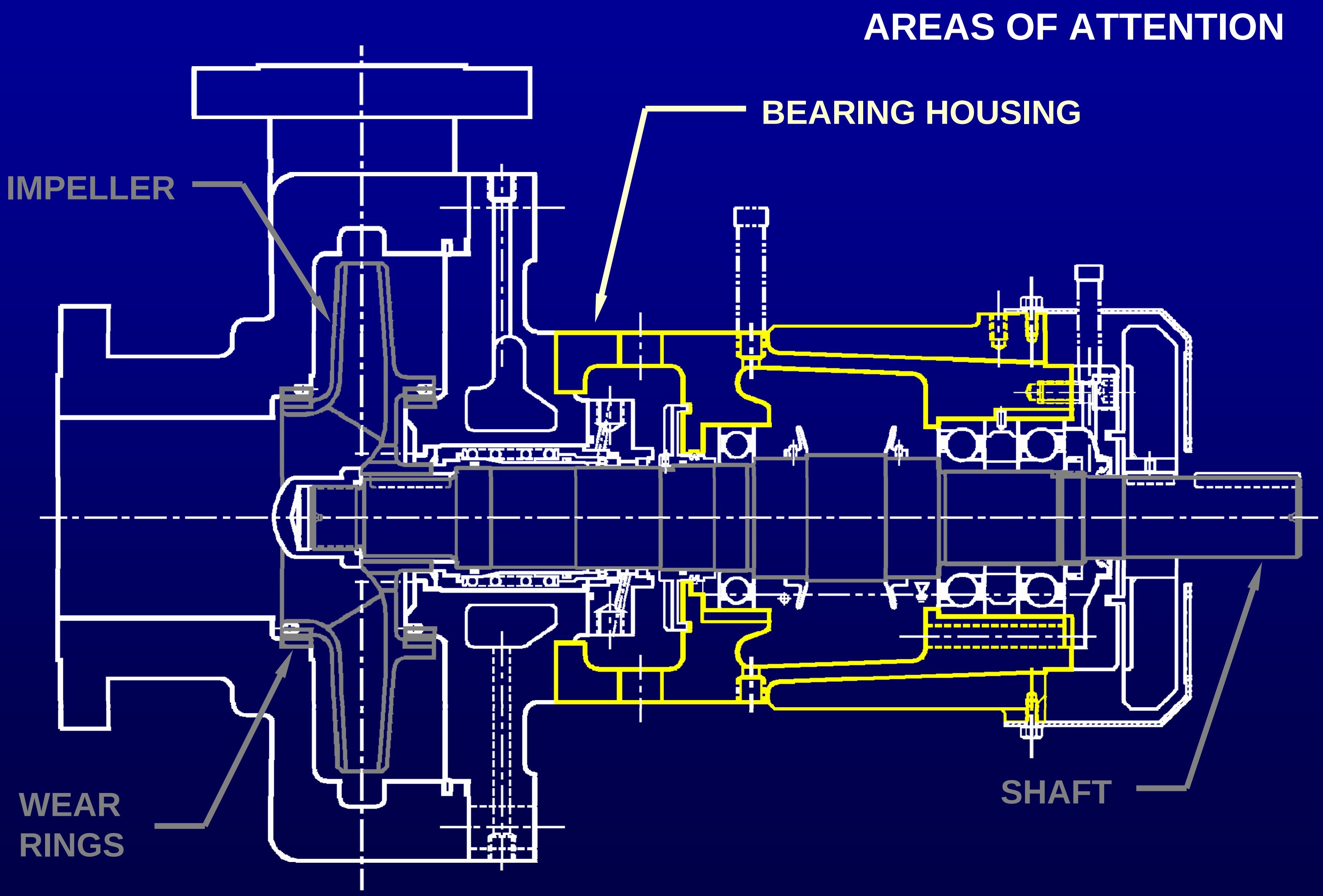
KEYWAY CORNER RADIUS

MANUFACTURING MATERIAL:

ORIGINAL	NEW
AISI 304	AISI 420

SHAFT END / MATERIAL IMPROVEMENT

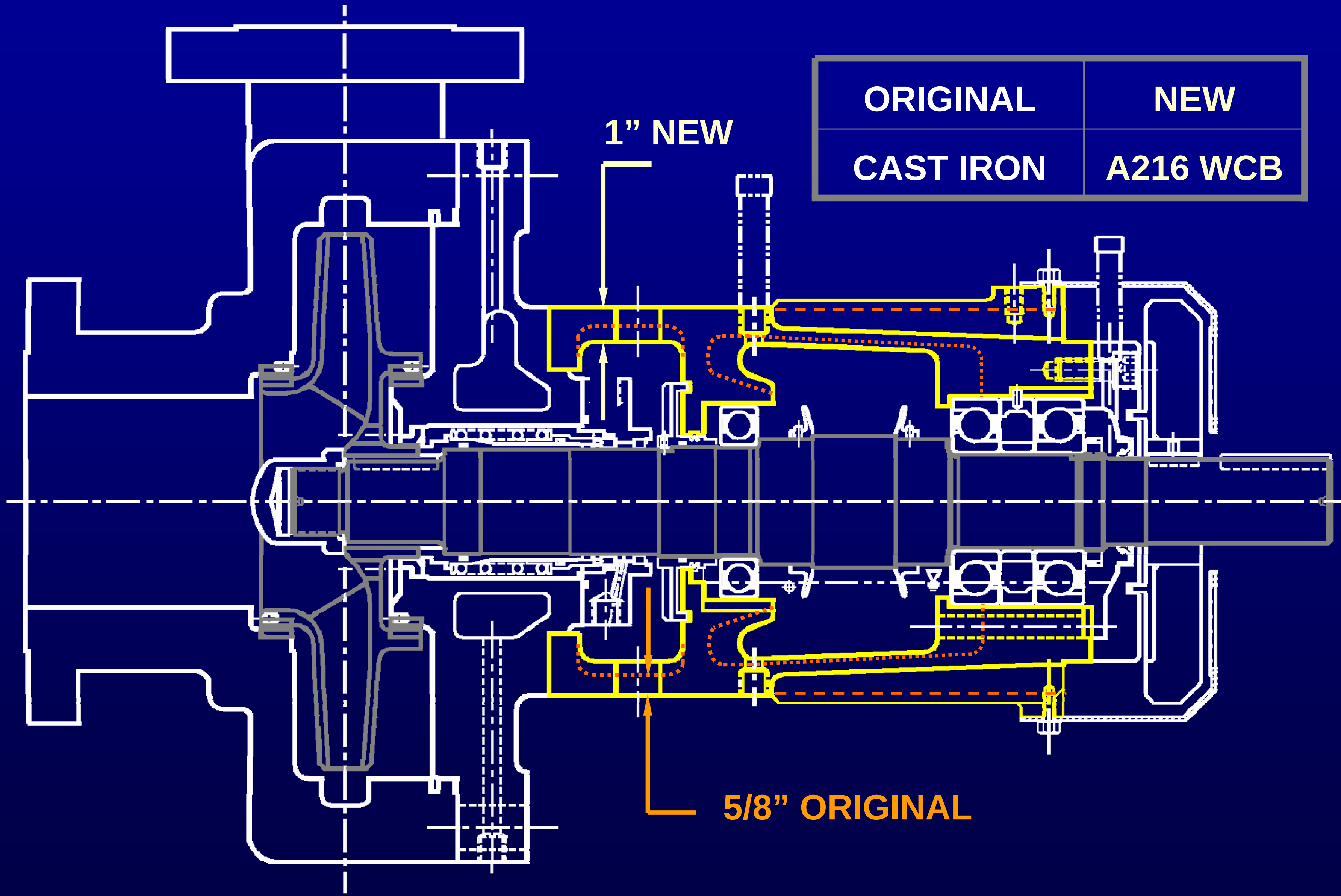
PUMP UPGRADE



PUMP UPGRADE

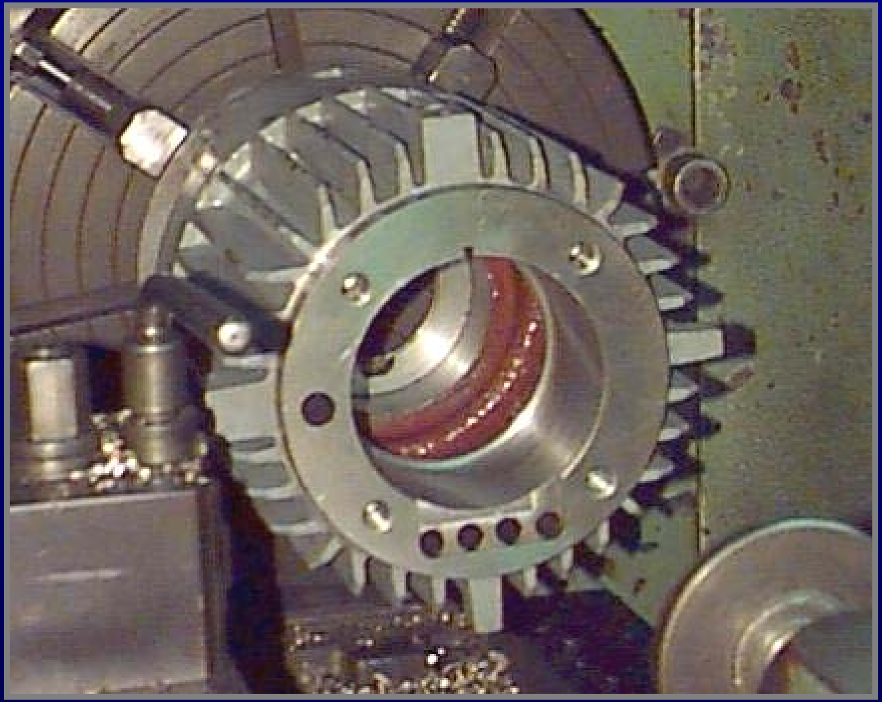
BEARING HOUSING IMPROVEMENT

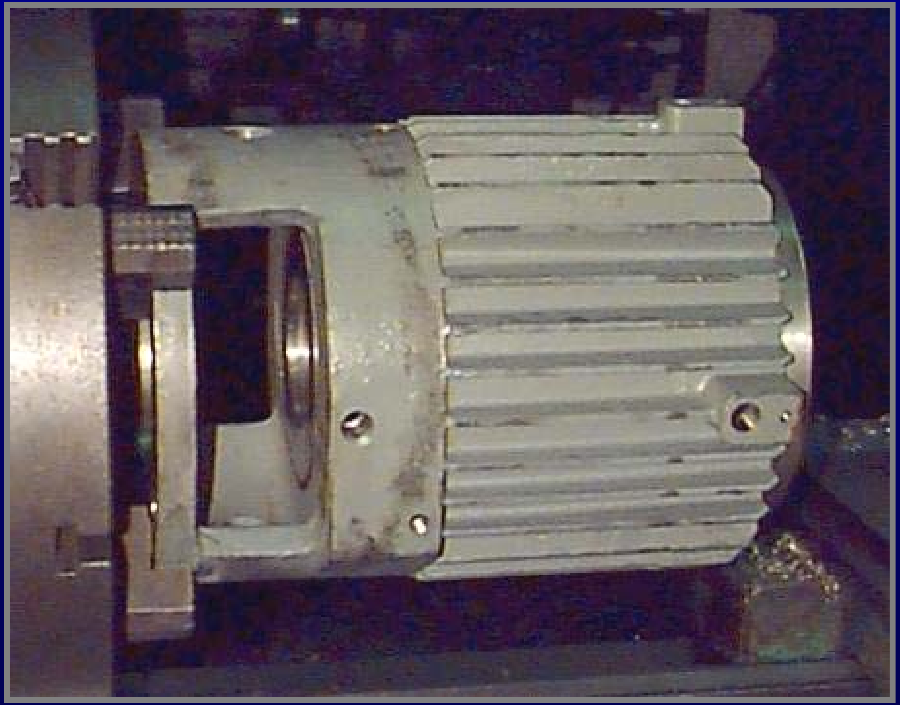
ORIGINAL	NEW
CAST IRON	A216 WCB



PUMP UPGRADE

BEARING HOUSING IMPROVEMENT

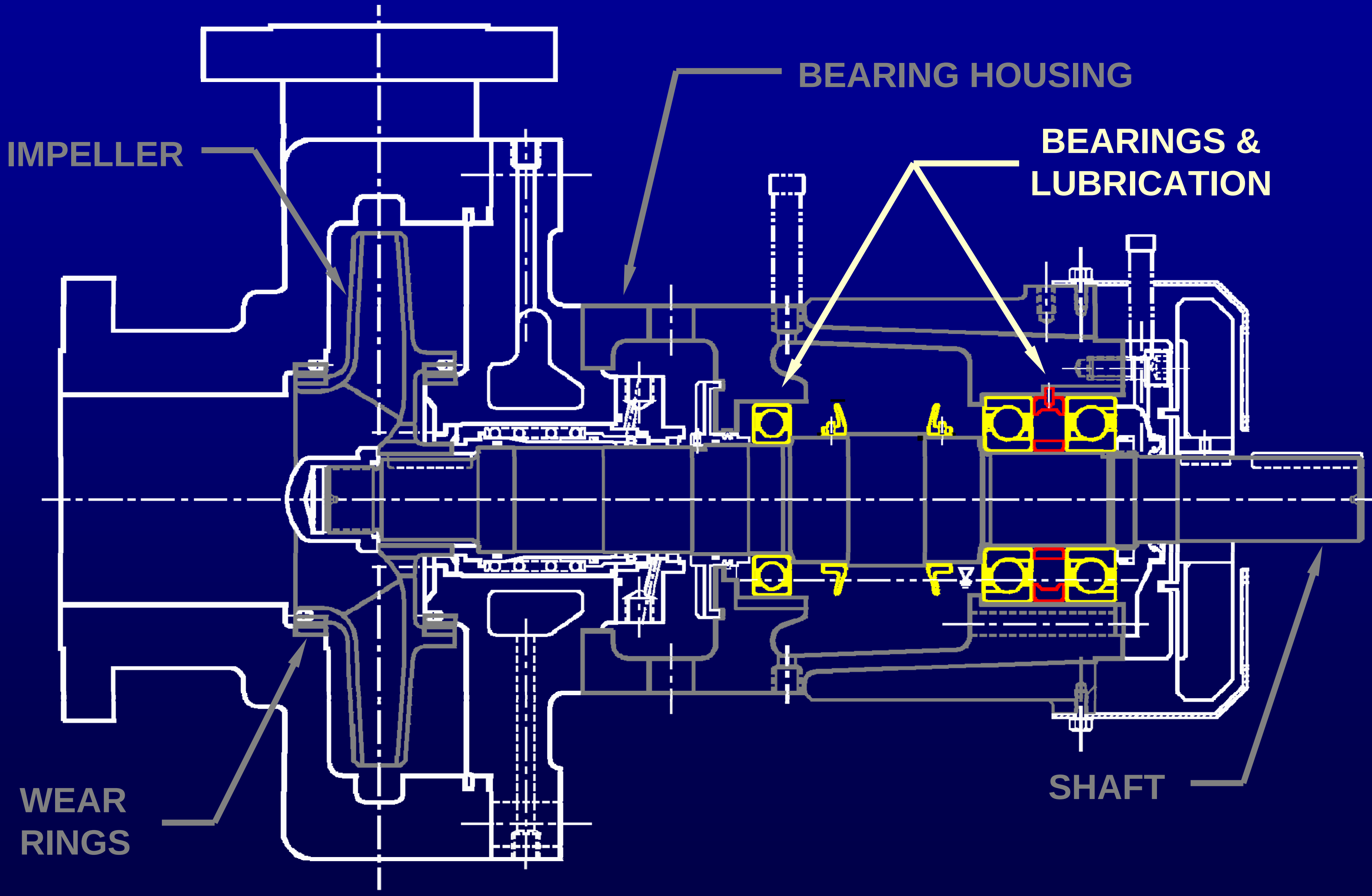




IMPROVED BEARING HOUSING

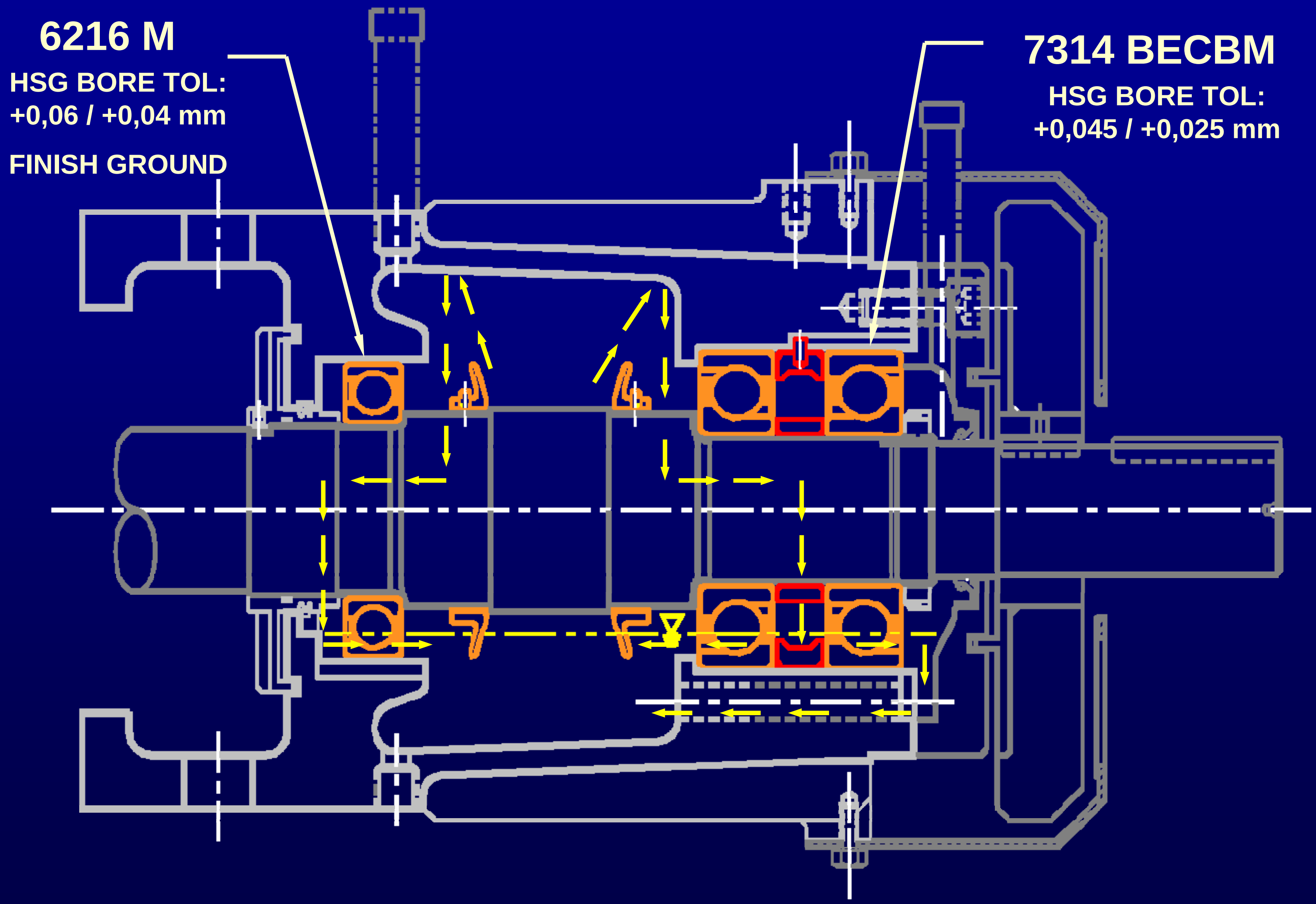
PUMP UPGRADE

AREAS OF ATTENTION



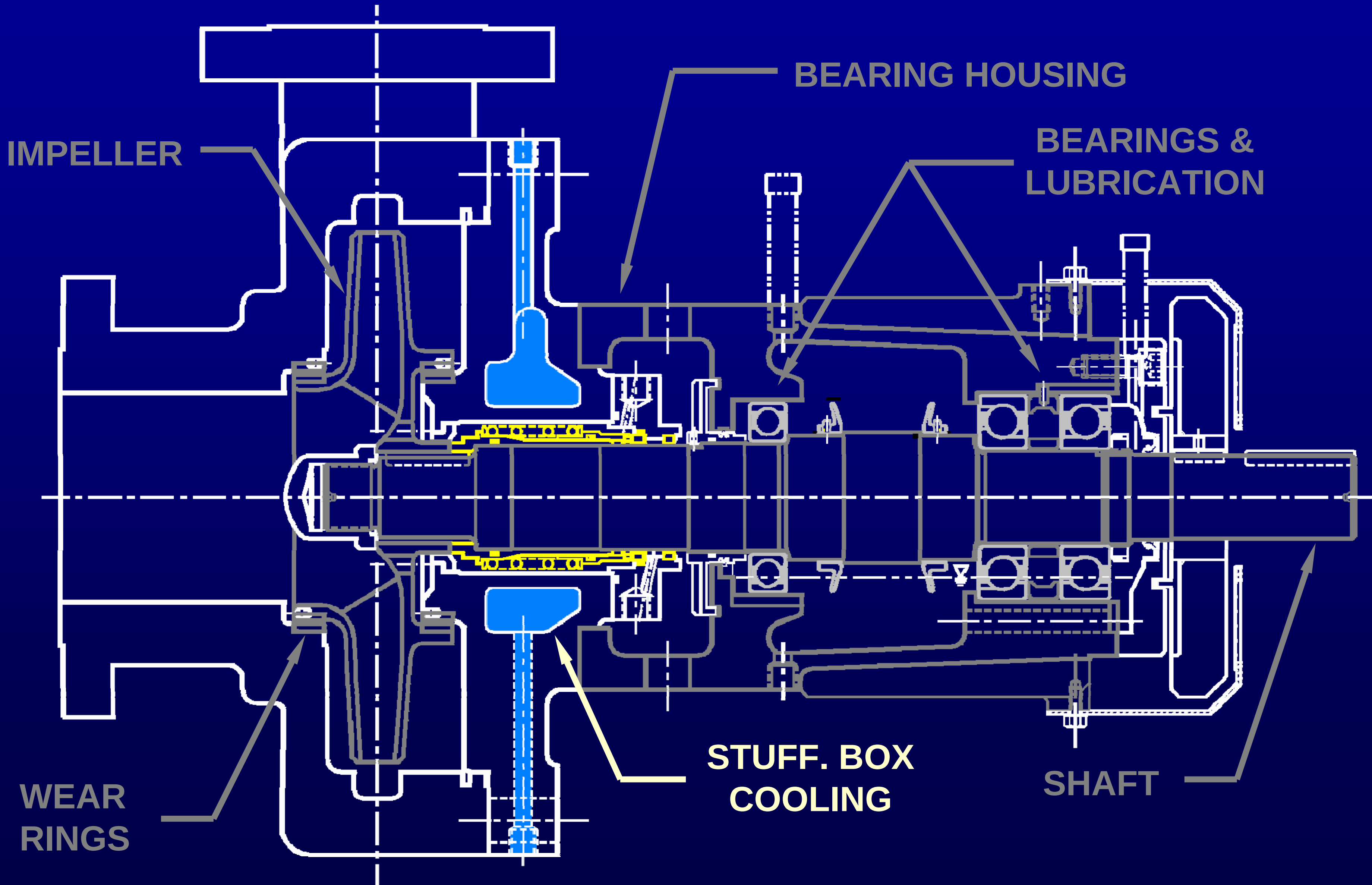
PUMP UPGRADE

BEARINGS & LUBRICATION IMPROVEMENT



PUMP UPGRADE

AREAS OF ATTENTION



PUMP UPGRADE

SUMMARY OF MAIN IMPROVEMENTS

		BEFORE	AFTER
IMPELLER	• PARTIAL VANES	MISPOSITIONED	EXTENDED & CORRECTED
	• MAIN VANES AT INLET	IMPROPER TRIM	TRIMMED IN PATTERN
	• VANE LEADING EDGES (ALL)		ROUNDED & THINNED IN PTRN
	• MATERIAL	AISI 304	18 Cr – 16 Mn
WEAR RINGS	• IMPELLER / CASING	AISI 304 / AISI 304	1 AISI 304 + Cr / 18Cr-16 Mn
			2 18 Cr-16 Mn / AISI 304
SHAFT	• L3/D4	34.3	18.4
	• END THREAD SIZE / FILLET RADIUS	M38 + FILL. RAD. 3/32”	M48 + FILLET RADIUS 5/32”
	• RADII AT SHOULDERS / CORNERS	3/32” AT END / SHARP KW	1/4” AT END / 1/32” AT KW
	• MATERIAL	AISI 304	AISI 420
BEARING HSG	• THICKNESS AT TRANSITION PIECE	16 mm (5/8”)	25 mm (1.0”)
	• MATERIAL	CAST IRON	CAST STEEL A216 WCB
BEARINGS	• RADIAL / THRUST	6215 / 7313 BG	6216 M / 7314 BGM
LUBRICATION			ENHANCED / CIRCULATING
MECH. SEAL	• STUFF. BOX COOLING	NO	YES
COUPLING		GEAR/LUBRICATED	DISC PACK / NON-LUBR.

UPGRADED PUMP TEST

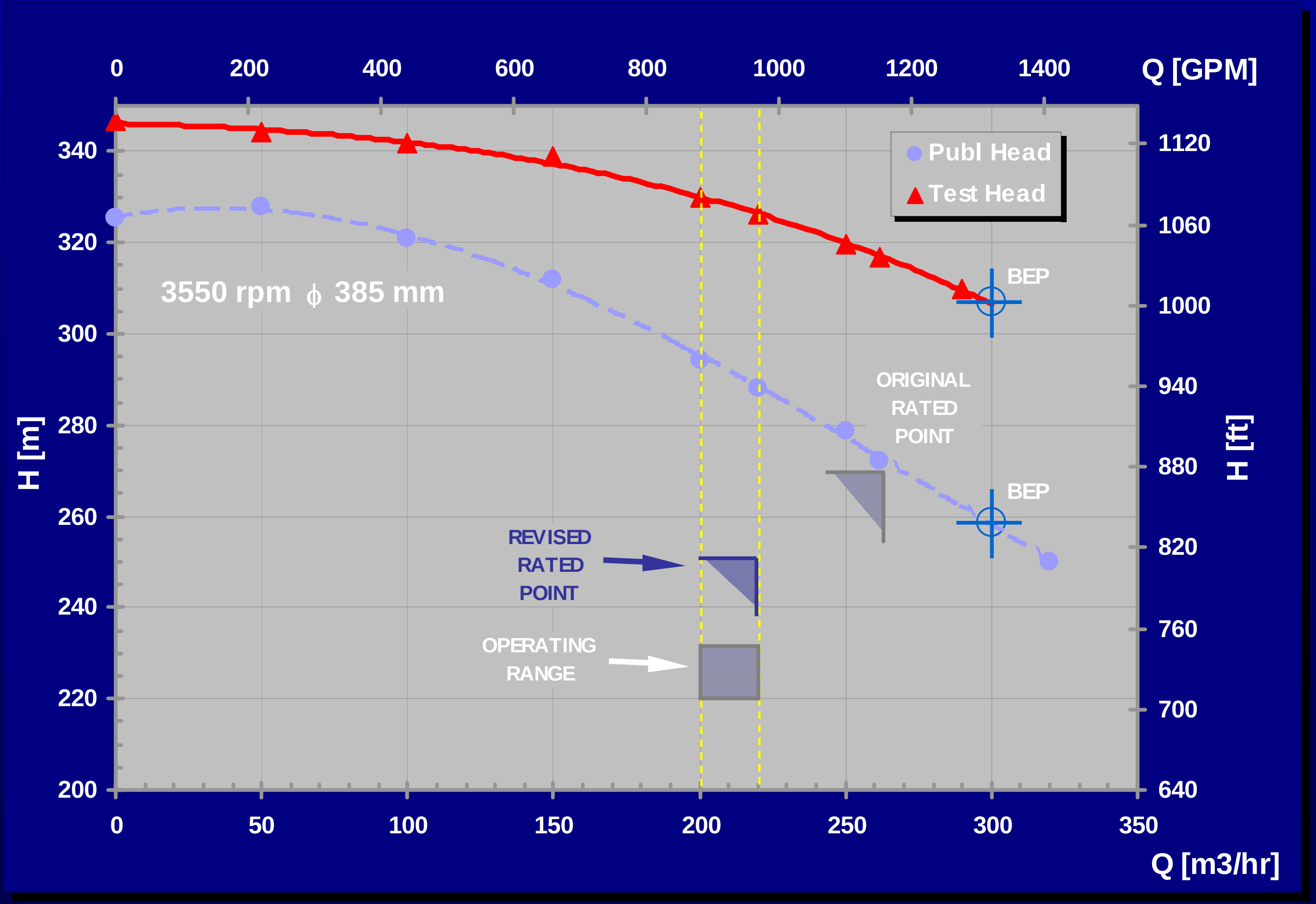
STAND-TESTING OF UPGRADED PUMP

OBJECTIVES:

- **Determine actual performance for modified impeller.**
- **Quantify actual NPSHR.**
- **Reduce effects of adverse operating conditions:**
  - **Trim impeller of pump "B" to reduce part load operation.**
  - **Rework impeller, if required, to help prevent cavitation.**
- **Guarantee trouble-free operation at the plant.**

UPGRADED PUMP TEST

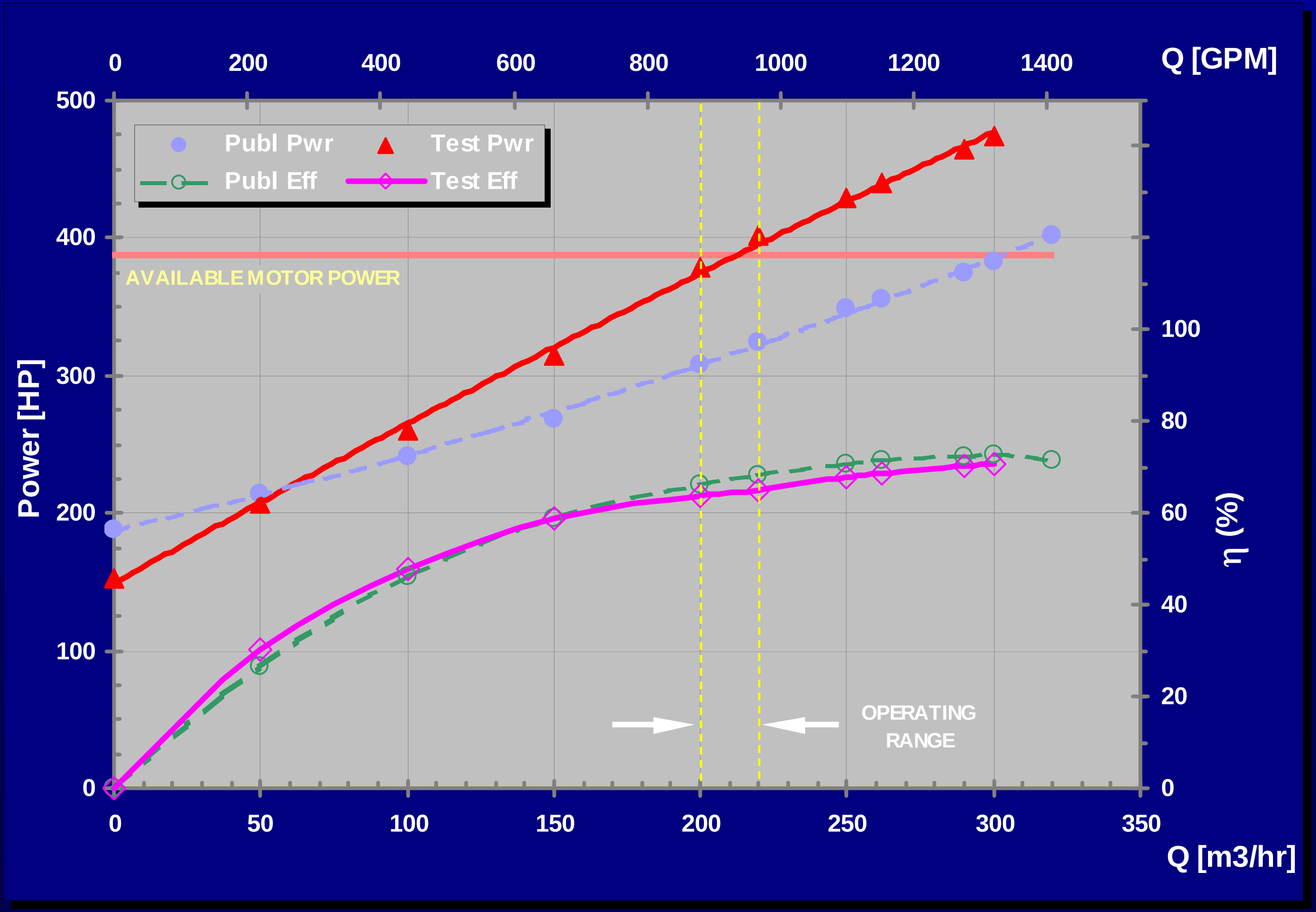
RESULTS OF PERFORMANCE TESTING



HEAD VS FLOW – FULL SIZE IMPELLER

UPGRADED PUMP TEST

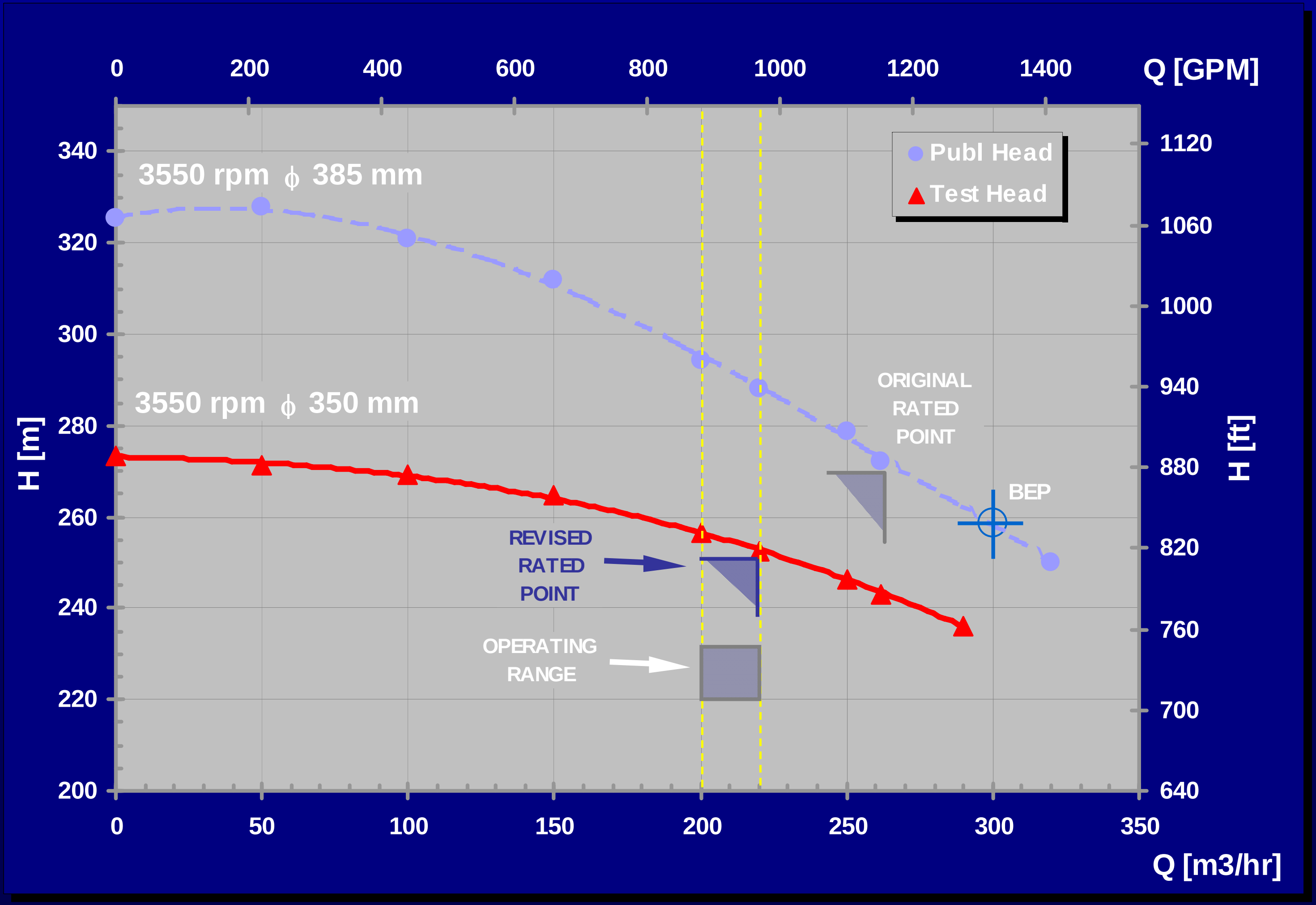
RESULTS OF PERFORMANCE TESTING



PWR & EFF VS FLOW – FULL SIZE IMPELLER

UPGRADED PUMP TEST

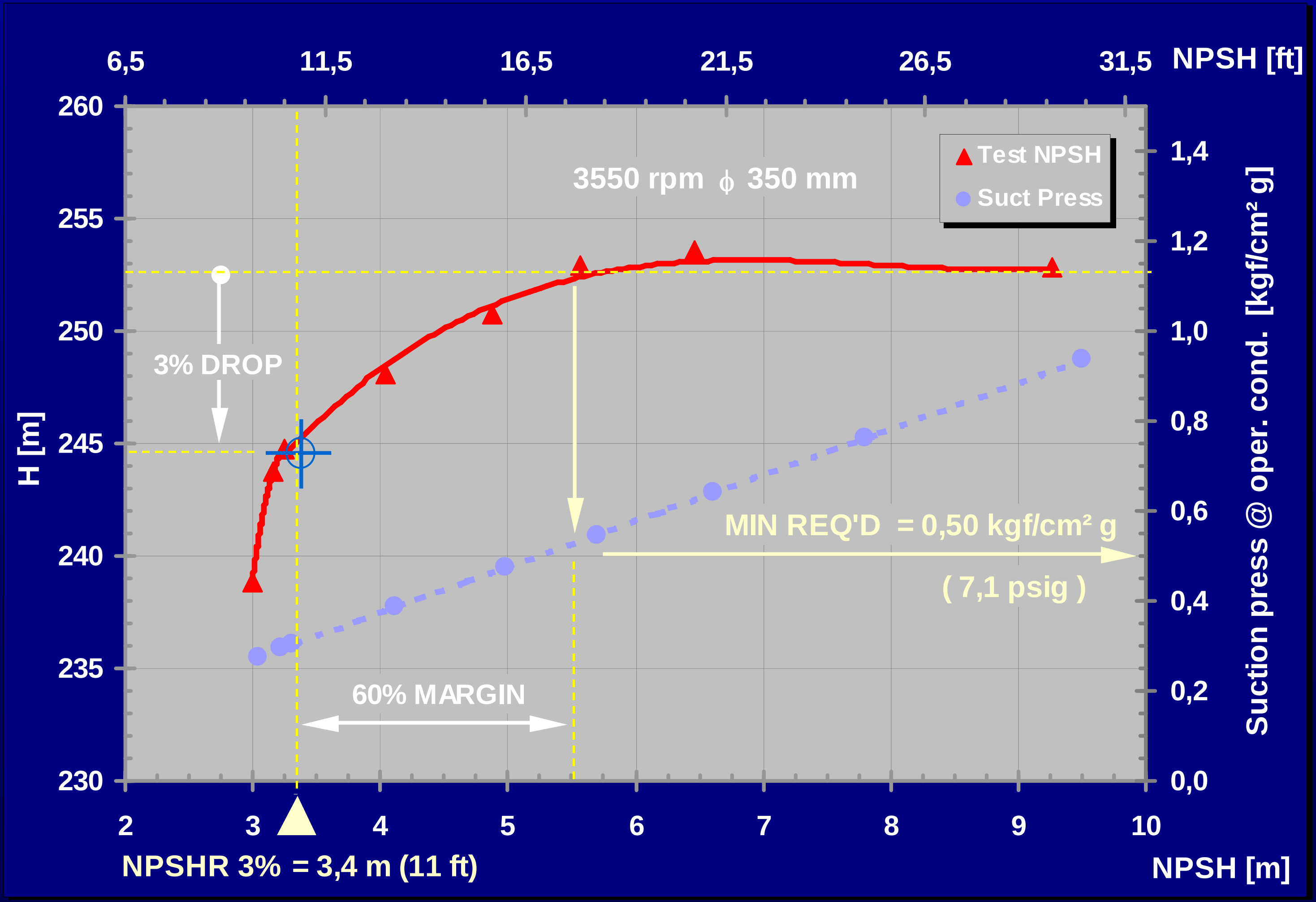
RESULTS OF PERFORMANCE TESTING



HEAD VS FLOW – TRIMMED IMPELLER

UPGRADED PUMP TEST

RESULTS OF PERFORMANCE TESTING



NPSHR @ 220 m^3/h (970 GPM) – TRIMMED IMPELLER

UPGRADED PUMP TEST

TEST CONCLUSIONS

- **Performance of modified impeller was determined**

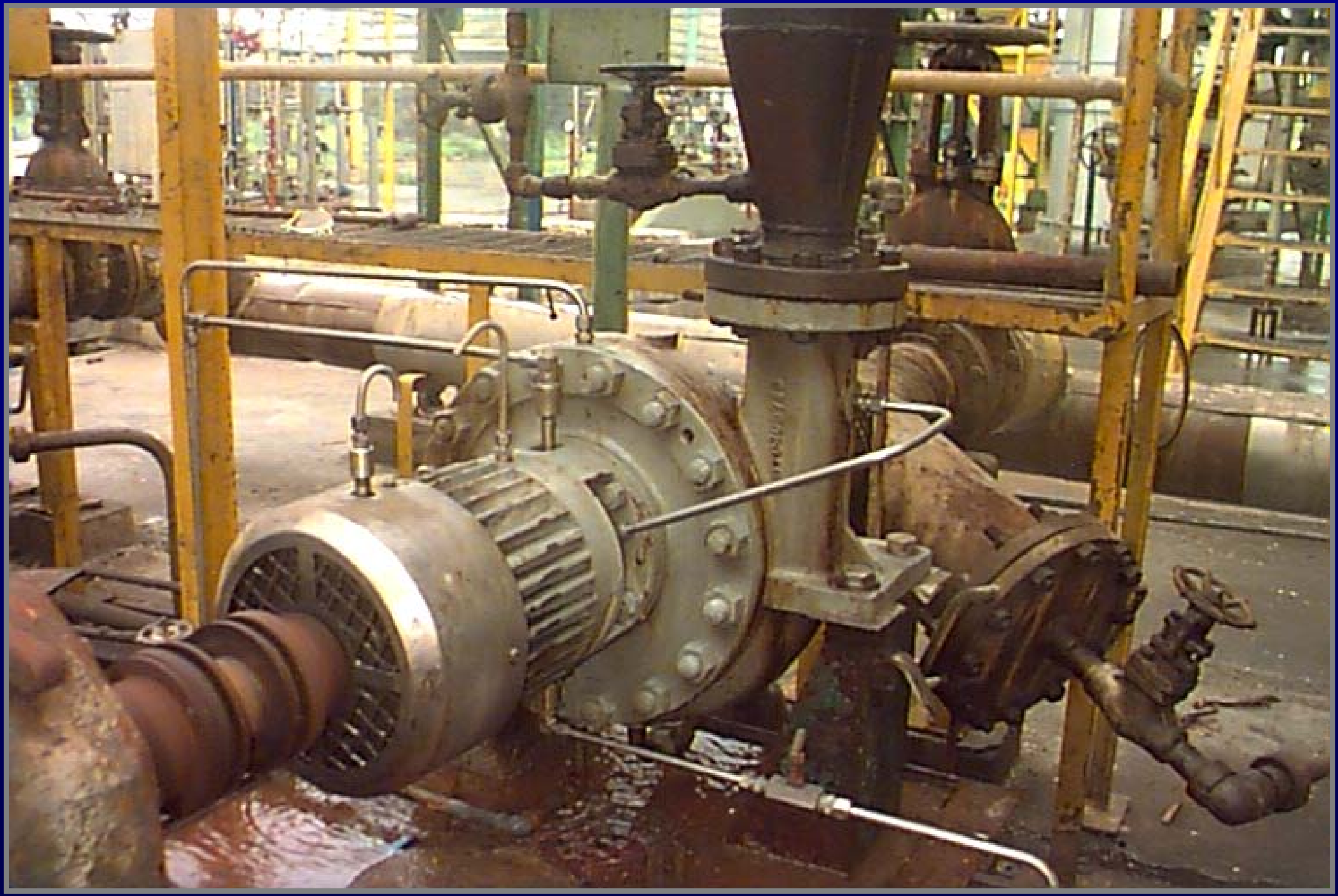
Head:	**Larger due to partial vanes**
BEP:	**Coincident at 300 m^3/hr (1320 GPM)**
Efficiency:	**Coincident with original**
NPSHR:	**15% lower than expected**

- **Adjustments for revised conditions of service:**

Pump “A”:	**Full-size impeller @ 3150 rpm**
Pump “B”:	**91% dia impeller @ 3550 rpm**
	Min suct. press.: 0.5 kgf/cm^2 g (7.1 psig)
	Required NPSH Margin: 60%

UPGRADED PUMP "A"

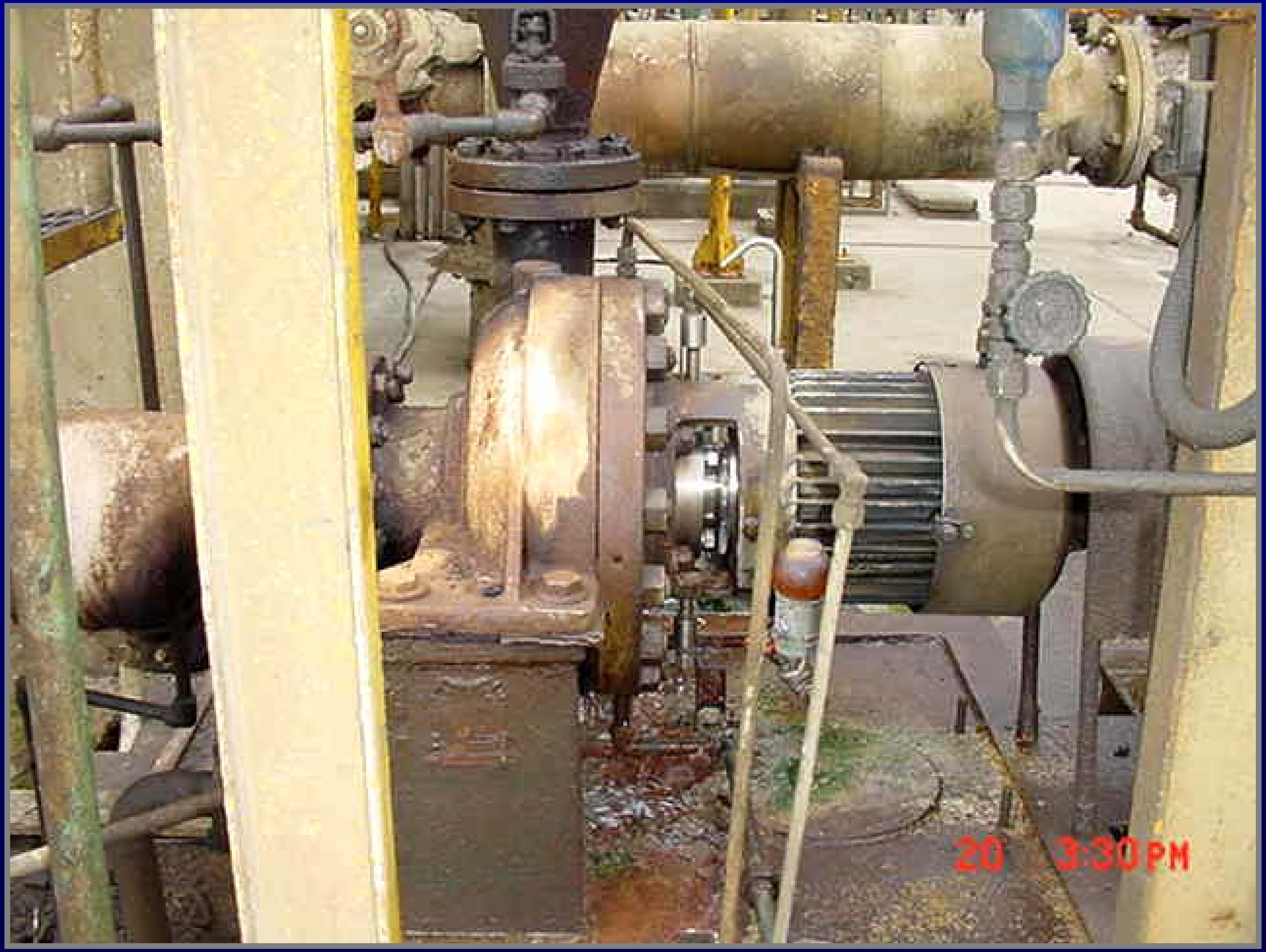
PUMP IN SERVICE – MAY 2000



MAIN PUMP INSTALLED SEPT 1999

UPGRADED PUMP "A"

PUMP IN SERVICE – MARCH 2002



MAIN PUMP INSTALLED SEPT 1999

UPGRADE RESULTS

COST – LEAD TIME COMPARISON

	PROS - CONS	*COST & LEAD TIME*
PUMP REPLACEMENT	▸ Field work required ▸ Larger cost	• ENGINEERING $ 3,0 K • 1 PUMP & DRIVER $ 90,0 K • 2 YR SPARE PARTS $ 5,0 K • FOUND. & PIPING $10,0 K TOTAL: $ 108 K 11 MONTH ON SITE
PUMP UPGRADE	▸ No field work required ▸ Less cost	• ENGINEERING $ 5,0 K • BRG HSG PATTERN $ 5,0 K • MAIN PARTS $ 17,0 K • MFG, ASSY & TEST $ 12,0 K TOTAL: $ 39 K 11 MONTH FINISHED

UPGRADE RESULTS

CURRENT UPGRADE PROGRESS – END 2002

MAIN PUMP "A"

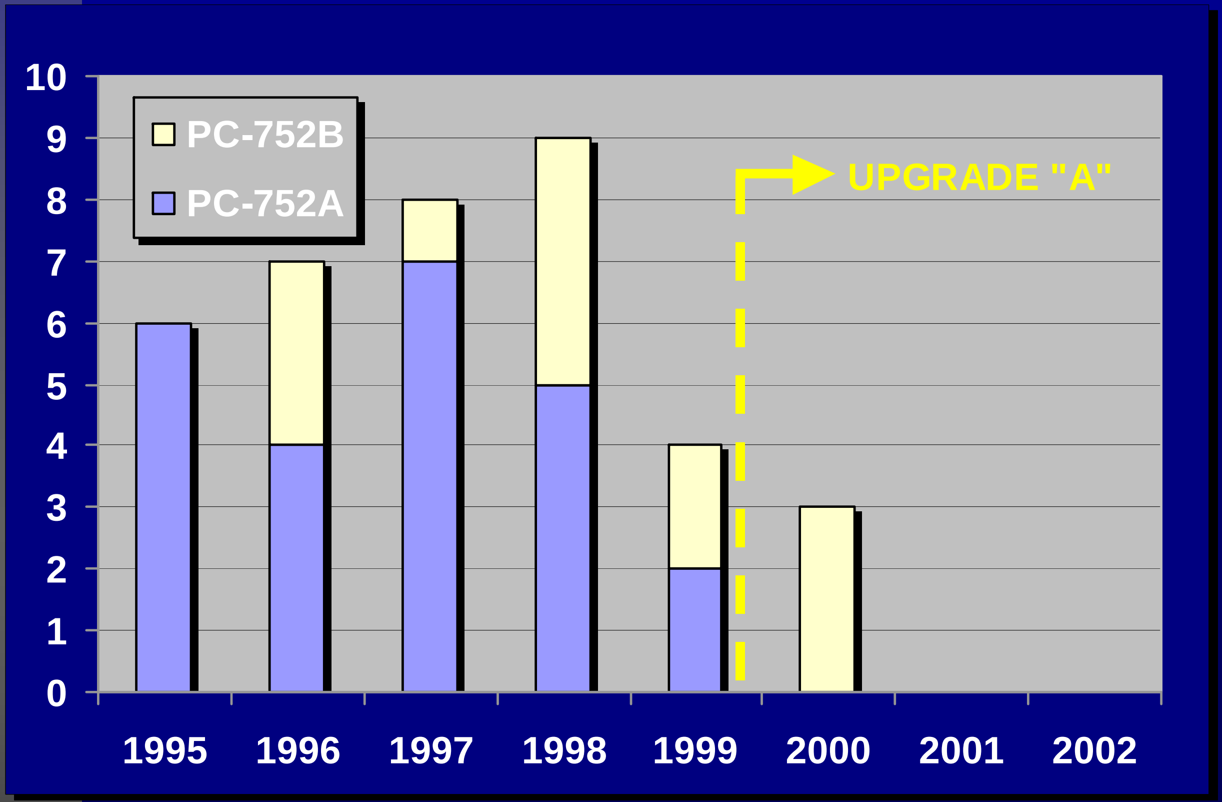
- **Fully upgraded**

STAND-BY PUMP "B"

- **Partially upgraded**
  - **Impeller & wear rings**
  - **Shaft end design & material**
- **Impeller size increased from 91% to 96% (370 mm)**
  - **Flow requirement not reached**
  - **Measured suct. press.: ≈ 0.25 kgf/cm² g (3.6 psig)**
  - **Full cavitation, NPSH margin < 0**

UPGRADE RESULTS

RELIABILITY IMPROVEMENT – END 2002



MAIN PUMP "A"

- **Fully upgraded**
- **No failures**

STAND-BY PUMP "B"

- **Partially upgraded**
- **Failures at brgs & seal only**

Projected savings over 10 years: US$ 900 K

FAILURE HISTORY BEFORE AND AFTER THE UPGRADE

CONCLUSIONS

- Pump upgrade objectives were successfully achieved.
- Upgrade of existing pump was the best choice for a cost-effective solution.
- In-house engineering allowed a custom design with some features exceeding current mfr. specs.
- Impeller revised configuration is not an optimum solution, but provided a remarkable service life improvement.
- Detected design deficiencies played an important role on low reliability, but not on catastrophic failures.

LESSONS LEARNED

- **In general, improvement of existing equipment represents lower investment and lead time.**
- **Check your equipment for upgrade opportunities, specially if they exhibit low reliability.**

REFERENCES

RELIABILITY IMPROVEMENT OF END SUCTION PUMP IN SEVERE SERVICE THRU ENGINEERED COMPONENT UPGRADE

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THANK YOU !