2009 Sayano-Shushenskaya hydro disaster

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Topics

1. The risk
2. The loss
3. Risk management
4. Maintenance
5. The property insurance policy
6. Causation
7. Claims handling
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1 The risk
Hydro-Power Plant Sayano-Shushenskaya

Largest hydro power plant in Russia
6th-largest hydro power plant worldwide (2009)
Owner: RusHydro

Location:
- South Siberia, close to Mongolia, China and Kazakhstan
- Earthquake-prone Altai mountains
- 70 km southeast of Lenin’s exile from 1897 to 1900
Project

1960  Decision made
1978  First turbine generator in operation
1979  Unit 2 with temporary runner (400 MW)
1985  Last turbine generator synchronized
1986  Unit 2 receives regular runner

Note:
Period: 27 years (plan: 9 years)
2000  Formally commissioned

Period 27 years (plan: 9 years)
Civil constructions

Concrete arch-gravity dam
- Height: 240 meters
- Length: 1,000 meters

Penstocks: 194 meters

Spillways
- 11 gates: capacity of 13,500 m³/s (operation limit 7,500 m³/s)
- 2 gates for spring floods: capacity of 4,000 m³/s (built 2005-10)

Machine house:
290 meters long, 35 meters wide and 25 meters high

Picture source: Rostekhnadzor’s Act
The reservoir

Surface: 620 km²
Length: 320 km
Max. width/depth: 10 km/110 m
Main supplier: Yenisei River
2,700 houses given up during flooding
Power generation

Installed power: 6,400 MW (10 similar units)
Annual energy output: 25 TWh
Turbines: Francis type
  - Rotor diameter: 6.7 meters
  - Manufacturer: Leningrad Metal Plant
Generators:
  - 720 MW design
  - Manufacturer: Electrosila
Peak capacity at 4,000 MW (limitation of power lines’ capacity)
70% of energy for Rusal’s aluminum smelters
Re-Organisation

1993 and earlier, power industry:
- controlled by the Soviet ministry
- operated by Unified Energy System (UES),
  CEO: Anatoly Chubais

1993 Privatization (Boris Yeltsin)

2002 Hydro plants under control of grid load dispatcher to stabilize grid frequency

2004 Power industry reform: Federal Hydro Generating Company (100% subsidiary of UES) manages the hydro power stations

2008 UES becomes RusHydro. CEO: Vasily Zubakin

Major stakeholder: Russian state (around 60%)
2 The loss
The accident

- 17 August 2009, 8 a.m. local time
- Plant was working at 4,100 MW
- 300 people on ground due to shift change and planned maintenance work
- Nine of ten units running (unit 6 off for maintenance)
- Unit 2 producing 600 MW at 212 m water head pressure
- 8.15 a.m.: unit 2 breaks out of its foundation
- Gives way to a water flow of 360 m³/s

Picture source: unknown
Consequential damage

- Flooding of machine house, floors below and office buildings
- Partial damage to roof and walls of powerhouse
- Almost total loss of cooling system, battery elements, generator switches, drainage pumps, elevators, ventilation, cables, switching cabinets, compressor system
- Short circuits causing explosions of many oil transformers
- Oil leakage (100 tons) caused contamination of downstream trout farms
Consequential damage (cont.)

- Widespread power failure
- Fatal: penstock gates did not close immediately but after 75 minutes due to flooded electric safety system
- 75 fatalities, 62 from maintenance company
- CBI loss to Rusal’s aluminum smelter
- RusHydro’s price at the LSE: -30%, in Moscow: -10%
- Positive:
  - wicket gates of unit 5 closed
  - dam seems to be unaffected
The plant on 22 August 2009

Spillway (13,500 m³/s)

Penstocks (10 x 360 m³/s)

Oil-contaminated water

Admin building/control room

Powerhouse/machine hall

Five transformer stations

Picture source: Cunningham Lindsey Russia
3 Risk management
2007 risk inspection

Inspected by Suregrove, London

Major findings

- “None of the sets exceeded its design life of 30 years”
- Vibration monitoring program “below industry standard”
- Predictive maintenance “not practiced to any great extent”
- Turbine generators “serviced annually and overhauled every 4 to 6 years… takes up to 200 days”
- Portable vibration monitoring equipment used for generators before and after maintenance
- Regular vibration monitoring during normal operations “not conducted”
2007 risk inspection

Major findings (cont.)

- Units 1 and 5 with joint load control system (RAKURS)
- Other units, switchyards and distribution system controlled via “antiquated, panel-mounted analogue systems”
- Automatic shutdown of units only in case of over-speed

Ratings:

- **Average** compared to other similar risks surveyed worldwide
- **Above average** compared to other similar risks surveyed in the former Soviet Union
Plant originally designed for constant base load but used since years in regulating mode.

Very narrow recommended working band (zone III) at high efficiency.

Wide, not recommended area (shaded zone II) has to be crossed during regulating mode.

At 08:13 unit 2 was in the middle of zone II.
2007 risk inspection

Some critics

- Risk engineer with “22 years experience in all aspects of the oil, gas and petrochemicals industry”
- The plant was inspected on just one day
- The GOST 5616-72 states that the lifetime of generator should “not be shorter than 20 years”.
- On 17 August 2009: Unit 2 was 29 years and 10 months old
- The change from base load to regulating mode (start in 2002) was not mentioned
- Missing fail safe mode of penstock gates was also not mentioned
- The plant’s long history of problems (cavitation, poor construction et al) was not part of the report
Sayano-Shushenskaya was a wake-up call

In 2011 the government requested an investigation of 60 medium-sized and large hydroelectric plants in Russia by Rostekhnadzor.

Defects observed:

- 29%: Relevant working documents missing
- 15%: Requirements by Rostekhnadzor not fulfilled
- 14%: Instructions to monitor the plant’s safety missing
- Others: Limitation of water flow caused by defects (11%), design limits exceeded (10%), safety requirements violated (9%), operating staff insufficiently qualified (7%), coordinated business continuity plans missing (3%)

General problems: Insufficient implementation and/or controlling of safety rules, as well as obsolescence of the majority of the plants.

Consequences: Insufficient amount of controlling instrumentation, extreme wear and tear and insufficient transparency of information.
4 Maintenance
Rostheknadzor report (Oct 2009)

Last major overhauls on unit 2 (in accordance with manufacturer guidelines):

- 2000 (runner, turbine bearing, shaft and cap)
- 2005 (excitement regulator replaced, reconstruction of motor valve control, runner, turbine bearing)

Last service maintenance in 1Q2009:

- Repairs on head gates, flow channel, runner, wicket gates, generator bearing, etc.
- Installation of vibration-control detectors (Rakurs), not commissioned
- Repair time: 1,409h (1,488h planned).

General problem: cavitation - cracks (up to 15 mm) in the runner
Rostheknadzor report (Oct 2009)

**Turbines:** After 50,000 h operating time, the scope of repair increased considerably. Consequence: 4-5 units to be repaired annually on average.

**Generators:** Special production series for this plant. After that, production of generators and spare parts ceased. The plant “has almost run out of spare parts”.

**Automated process control system:** Obsolete. Operated for over 20 years, with a designed service life of 8-10 years. Spare part production discontinued by 1999 at the latest.

RusHydro management did not fulfill the order to improve the severely deteriorated equipment or provide automatic range control.

**Preventive maintenance:** only by visual inspections, no NDT.
Nov 2003: maintenance functions were transferred to a newly established contractor company Hydroenergoremont (wholly owned by HPP Sayano-Shushenskaya).

Scope of maintenance:
- 90% of the mechanical and electrical work, and
- 50% of the civil works.

The remainder is contracted to other companies (as before).

The maintenance work is put out to tender.

After the (shorter than planned) maintenance in 1Q2009 vibration increased.
5 The property insurance policy
Some relevant details

**Original property policy: И4-2337808/10-2, dd 25 December 2008**

Section I: All risks & CAR

Excluded events: in case of breach of safety rules and norms, … established by applicable law and normative statements if it was the direct cause of an insured event;

Section II: Mechanical breakdown

Excluded: wear and tear, … if a result of violation of normative-engineering specifications on equipment operation …. However, subsequent damage … shall be indemnified.

- Limit: USD 200m EEL with automatic reinstatements
- Dams excluded
- Insurer’s representative empowered with appropriate authority shall be part of the investigation commission
- Suspension of payments possible if law enforcement agencies institute criminal proceedings against executives of the Insured … until the criminal investigation is completed
A) **Advance payment** to be paid after the following documents have been submitted to the Insurer:

- application for advance payment,
- photos of damaged property,
- inventory cards of damaged property or other documents confirming the Policyholder’s property interest in injured property,
- estimate of cost of repair (reconstruction) works, and
- schedule of fulfillment and financing repair (reconstruction) works.

Shall be made within **5 working days** upon submission of above documents. In the event of an unreasonable delay in making advance payment, … the Insurer shall pay a **penalty of 1%** of the delayed advance payment **per delayed week**.

B) Within **three working days** of receipt of the documents …, forward the **written decision on recognition or non-recognition** of an insured event.
Some relevant details

Original policy: И4-2337808/10-2, dd 25 December 2008

C) Final insurance indemnity within five working days of the following being submitted to the Insurer:

- documents confirming the purchase of property or equipment to replace damaged property or equipment,
- documents confirming the expenses incurred on repair of damaged property,
- other documents and expert reports in accordance with the Insurer’s requirements (contracts, certificates, licenses of expert organizations), and
- other documents confirming charges indemnified hereunder.

Penalty of 1% of the final insurance indemnity per delayed week.

- Period: 1 January 2009 00:00 – 31 December 2009 00:00
- TSI: RUB 262,863,790,665.30 (around USD 1bn) - Deductible: RUB 1.25m (USD 50,000 – only PD)
- Jurisdiction: Russia - arbitration clause
- Retention of Insurer: 0.8%
Causation
Rostheknadzor’s analysis (Oct 2009)

Investigation committee of 29 individuals published the “Act of technical investigation into the causes of accident” only 6 weeks after the event

- Following the repair work in early 2009, the level of vibration was higher than the acceptance level
- Excessive vibrations for the last 13 minutes were not stopped by persons responsible locally
- At least 6 (of 80) nuts were missing

Top of the cap of flooded unit 10

Wicket gate

Studs
Vibration measurements after last service maintenance

Unit 2

- Maximum vibrations
- Average vibrations
- Maximum acceptable vibrations 160 µm

Data on 17 Aug 2009
- 8.00 a.m. 600 MW 600 µm
- 8.13 a.m. 475 MW 840 µm

Picture source: Rostekhnadzor’s Act – 3 October 2009
Organisational defects

Since 2003, the plant was used to perform secondary control of reactive power and frequency for the Siberian power grid.

The number of transfers was not regulated or limited. The time of presence in zone II and the speed of its passing were set w/o approval of the manufacturer.

On 16 August 2009, a fire occurred in HPP Braskaya. HPP Sayano was forced to take over automatic regulation by Siberian Unified Dispatching Control Center.

Unit 2 was appointed as priority for the load change. At 8.13 a.m. it was in zone II to meet grid demands…

Picture source: Rostekhnadzor’s Act – 3 October 2009
“The main cause of the accident was the failure to promptly stop unit 2 and find out the reasons for vibration”

Poor operational and maintenance standards

Non-compliance with safety features

Irresponsibility and carelessness of staff of all levels

Low level of authority on site

Changes in operation modes without taking into consideration the original design

Lack of timely replacement of equipment approaching end of life cycle

And: The event could have been avoided…
Claims handling
Initial response actions

The immediately initiated closing of all head gates prevented greater flooding.

Overtopping of dam was prevented by opening spillway with an external diesel unit.

Water pumped out by 22 August

Concern spillway

- Not for permanent use, especially not in harsh winter (-45°C)
- Flood risk in spring time due to melting snow
- Chainsaws and open flames used to maintain the flow
- Long-term damage in stilling basin unknown
## Repair and replacement schedule

<table>
<thead>
<tr>
<th>Hydraulic unit</th>
<th>Activity</th>
<th>Commissioning date</th>
</tr>
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<tbody>
<tr>
<td>6</td>
<td>Provisionally repaired</td>
<td>24 Feb 2010</td>
</tr>
<tr>
<td>5</td>
<td>Provisionally repaired</td>
<td>22 Mar 2010</td>
</tr>
<tr>
<td>4</td>
<td>Provisionally repaired</td>
<td>2 Aug 2010</td>
</tr>
<tr>
<td>3</td>
<td>Provisionally repaired</td>
<td>22 Dec 2010</td>
</tr>
<tr>
<td>1 &amp; 7</td>
<td>Replaced</td>
<td>15 Mar 2012</td>
</tr>
<tr>
<td>8</td>
<td>Replaced</td>
<td>15 Jun 2012</td>
</tr>
<tr>
<td>9</td>
<td>Replaced</td>
<td>21 Dec 2012</td>
</tr>
<tr>
<td>10</td>
<td>Replaced</td>
<td>4 Mar 2013</td>
</tr>
<tr>
<td>9</td>
<td>Replaced</td>
<td>21 Dec 2012</td>
</tr>
<tr>
<td>6</td>
<td>Replaced</td>
<td>Jul 2013</td>
</tr>
<tr>
<td>5</td>
<td>Replaced</td>
<td>Dec 2013</td>
</tr>
<tr>
<td>4</td>
<td>Replaced</td>
<td>May 2014</td>
</tr>
<tr>
<td>3</td>
<td>Replaced</td>
<td>Aug 2014</td>
</tr>
<tr>
<td>2</td>
<td>Replaced</td>
<td>12 Nov 2014</td>
</tr>
</tbody>
</table>

With four units in operation the spillway can be closed.
Repair progress unit 4 (restarted on 2 August 2010)

19 August 2009
16 September 2009
18 December 2010
1 March 2010
Legal action and political pressure

19 individuals, mainly from RusHydro but also from Rostekhnadzor, were found responsible for the accident by Rostekhnadzor

Legal actions

- Against seven individuals of senior management of RusHydro
- Against Hydroenergoremont
  - Accusation: misappropriation of RUB 24m (USD 1m)
  - Management affiliated with plant management

Raids of Insured’s and Insurer’s offices by police

(Further) 19 individuals blamed by Duma report.
Breach of safety norms: rejection of claim possible, but enforcement unlikely in a Russian court

“Non-disclosure of material facts”: had to be proved by Insurer

“Arbitration clause” means commercial court in Russia

VAT requested as indemnification

Actual (cash) value allegedly means book value in Russia

Significant differences between primary and reinsurance policy (no “back-to-back”)
Claims for insurance policies

Environmental: Claimant Rosprirodnadzor (Federal Forest Protection Agency) for RUB 469m. Court granted RUB 110.6m. Insured: RUB 30m.

Property: Calculated damage RUB 11.7bn. Insured: USD 200m.

Business interruption: RUB 10bn (RUB 33m per month). Not insured.

Life: RUB 1m, plus salary until children grow up, €25,000 (orphans), plus medical cost support.

CBI: Rusal requested RUB 1m. Settled below deductible.
Summary
Takeaways

1. Main causes of disintegration of unit 2: criminal action, human negligence and excessive vibrations

2. In consequence: a missing fail-safe design at the head gates caused long and severe flooding of the plant

3. The human tragedy of 75 fatalities was mainly driven by the timing (shift change) and poor safety regulation

4. Extensive property damage, business interruption, CBI and environmental losses

5. High level of loss mitigation prevented further large-scale damage

6. Too short and poor risk inspections overlooked deficiencies of relevance to underwriters

7. Ambiguities in the insurance and reinsurance policies delayed claims handling

8. Political risk still present; legal system not independent, evident during the claims handling process

9. This loss initiated a reconsideration of control mechanisms in the Russian power industry

10. This loss also intensified Munich Re’s own loss control engineering activities
Questions?

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Toronto, 6 October 2016
Klaus Wenselowski
March 1992

Head cover bolts of unit 1 at **Grand Rapids** failed, temporarily putting the 472 MW generating station out of service. Water flooded the lower portions of the powerhouse to the level of the tailrace within minutes.

Of the 120 studs holding the head cover on, 16 had complete fatigue failure, 61 had partial fatigue failure, 27 failed by fast fracture at the first thread in the tapped hole, ten failed by fast fracture under the nut, and six had failure of the head cover.

Unknown date

Failed head cover bolts were discovered in a powerhouse in Washington State. These bolts had also failed by fatigue fracture but, fortunately, the damage was discovered prior to failure of the head cover.
Sayano works well

7 September 2016 - Moscow, Russia.

RusHydro announces that daily output of the Sayano-Shushenskaya HPP has reached its maximum in almost 40 years of operation.

On 2 September 2016, the plant generated an all-time high of electricity – 110,306,939 kWh. The plant’s monthly output in August 2016 exceeded 3.1 TWh.

The record amounts of electricity produced by the Sayano-Shushenskaya HPP is a result of favorable hydrological conditions, as well as the modernization of the plant’s automatic reliability system which took place in 2015.

These factors, together with the launch of a new power transmission line connecting the Khakassia and Krasnoyarsk regions, made it possible to increase the maximum amount of the plant’s capacity delivered to the power system to 5,100 MW.
Other hydroelectric power plants on the Yenisei River

Mainskaya
- 321 MW (3 x 107 MW),
- Performs tailwater regulating of Sayano-Shushenskaya.

Krasnoyarskaya
- 6,000 MW (12 x 500 MW)