CVMR®

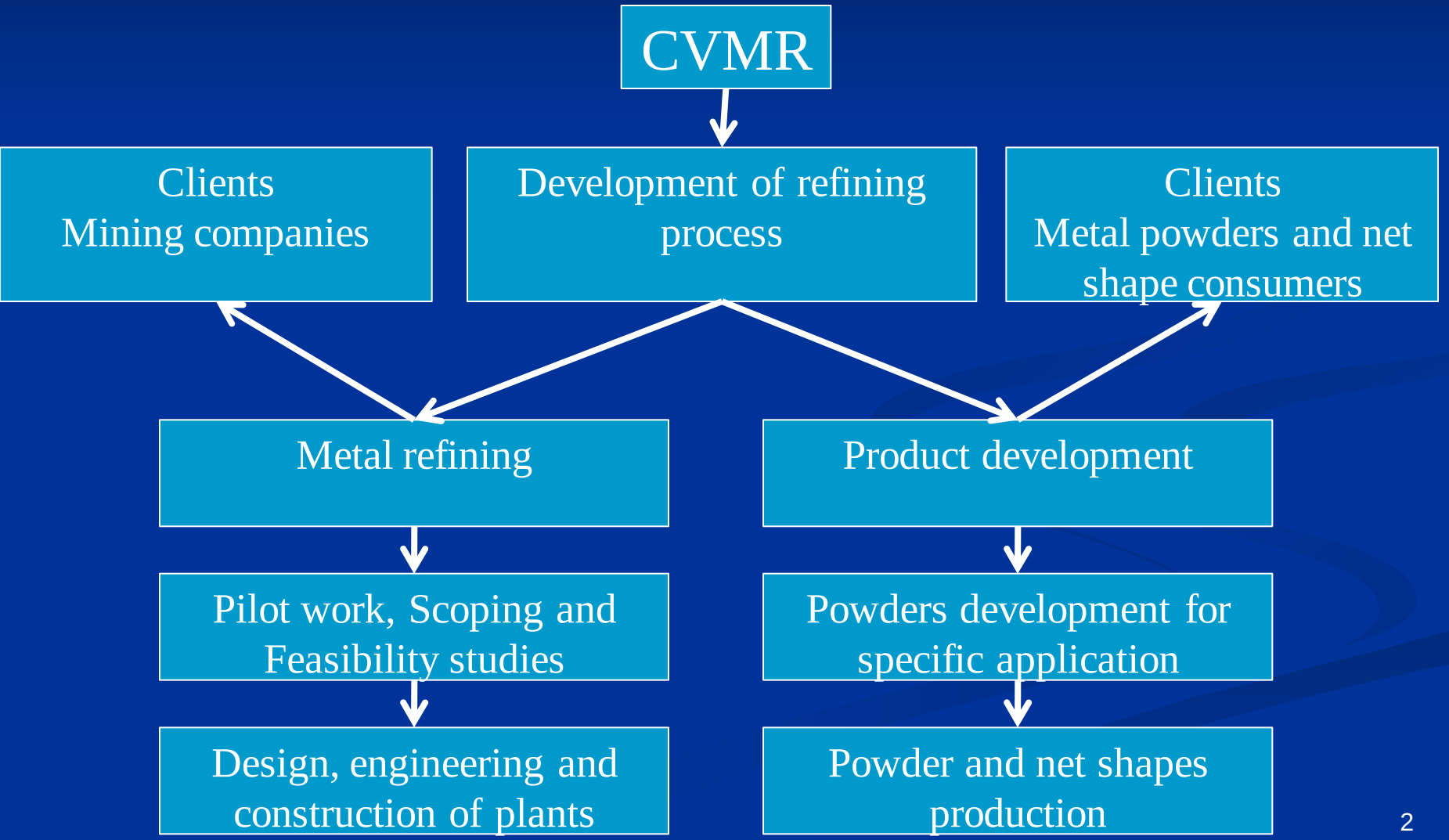
Chemical Vapour Metal Refining Inc.

Toronto, Ontario, Canada

Application of CVMR's process for decontamination of metals from radioactive impurities.

Las Vegas, October 2011

CVMR's Refining process.



Metal refining project

1st step

- Piloting, scoping study
- 1-2 years

2nd step

- Full scale piloting and Feasibility study
- 2-5 years

3rd step

- Plant design, engineering, construction and commissioning
- 3-5 years year

Powder project

1st step
- Test program
- From 1 to 100 Kg – 1-3 month

2nd step
- Production qualification run
- 100-1000 Kg – 3-6 month

3rd step
- Production
- 4-20 tons per year

Introduction to CVMR®'s Carbonyl Process

- Basic process developed since 1903
- Now: over 20% of world's annual nickel production uses carbonyl technology
- Carbonyl technology: based on the ability of nickel, iron, cobalt, etc. to form volatile metal carbonyl compounds
- CVMR® has modified old technology to suit the requirements of the new age
- Ongoing development by CVMR® since 1987

Introduction to CVMR®'s Carbonyl Process (cont'd)

- For Refining & Deposition:
  - 2 Ingredients: impure Ni + carbon monoxide = Nickel carbonyl gas $Ni(CO)_4$
  - Decomposed to pure Nickel products + carbon monoxide (re-used)
  - Products: Metal shapes, powders, foams or Metal compounds / alloys

CVMR®'s Carbonyl Process

- **Step 1: Carbonylation**

$$Ni + 4CO \xrightarrow[\text{produces}]{\text{cooling}} Ni(CO)_4$$

Solid Feed | Carbon Monoxide Gas | Nickel Carbonyl Gas

- **Step 2: Decomposition**

$$Ni(CO)_4 \xrightarrow[\text{produces}]{\text{heating}} Ni + 4CO$$

Nickel Carbonyl Gas | Solid Nickel/Iron Powder Product | Carbon Monoxide Gas (For Recycle)

Product Options for CVMR® process:

- Nickel pellets
- Powders: with different densities, morphologies
- Net shapes
- Coatings
- Foams

CVMR® Extraction Processes:

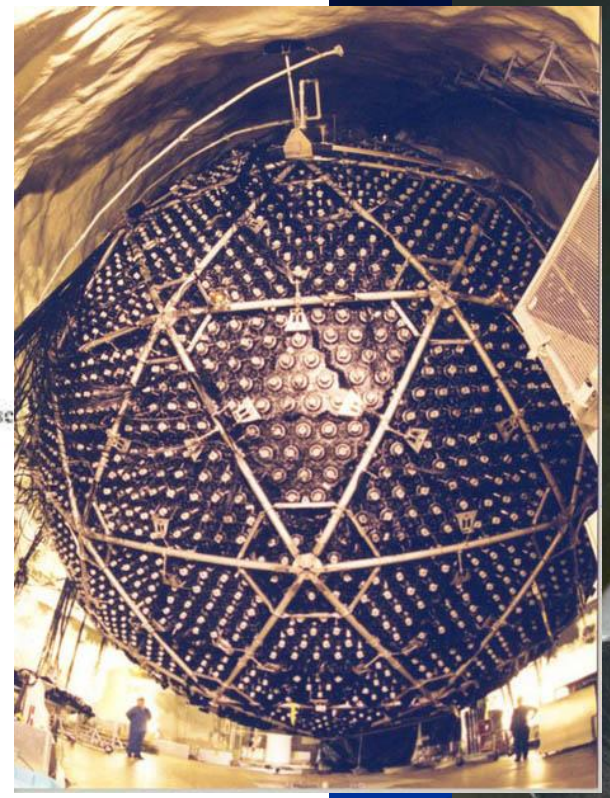
- Separate Nickel from impurities
- Flexible: without additional process steps
- Modular: choose the product to match demands

CVMR®'s Carbonyl Process Application to decontamination

- Project started in 1997
- SNO project indicated that CVMR's nickel has lowest level of radioactive contaminates
  - Th < $1.3X10^{-20}$ g/g
  - U < $0.4X10^{-9}$ g/g

CENBG
Centre d'Etudes Nucléaires de Bordeaux Gradignan
BP 120 • Le Haut Vigneau • F 33175 Gradignan Cedex

Téléphone (33) 05 57 12
Télécopie (33) 05 57 12 08 01



Ni plates from CVD

Results from low background gamma spectrose

- **Natural Radioactivity : Uranium chain**

U < 5 mBq/kg or $< 0.4\ 10^{-9}$ g/g
226Ra < 0.4 mBq/kg or $< 1.1\ 10^{-17}$ g/g

- **Natural Radioactivity : Thorium chain**

228Ra < 0.5 mBq/kg or $< 5\ 10^{-20}$ g/g
(If secular equilibrium → 232Th < $0.12\ 10^{-9}$ g/g)
228Th < 0.4 mBq/kg or $< 1.3\ 10^{-20}$ g/g

- **Cosmogenic Radioactivity**

56Co (T½ = 78.8 days) = 0.9 ± 0.2 mBq/kg
57Co (T½ = 271 days) = 2.2 ± 0.2 mBq/kg
58Co (T½ = 70.8 days) = 4.0 ± 0.5 mBq/kg
54Mn (T½ = 312 days) = 0.14 ± 0.05 mBq/kg

As expected, these cosmogenic isotopes are clearly seen in the Ni sample, but due to the rather short periods, their activities will strongly change from one sample to another one, depending on the exposure to cosmic rays and the delay time in the underground laboratory before measurement.

Ph. Hubert

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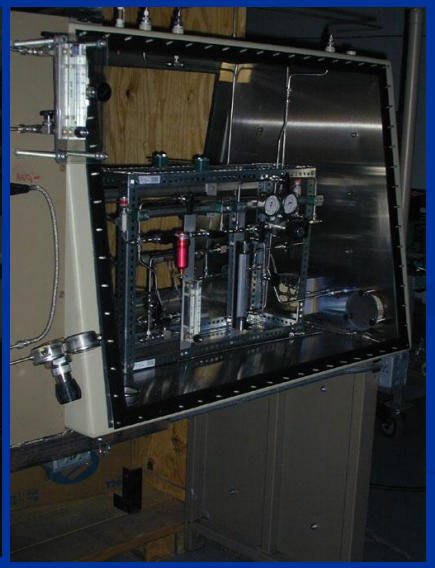
CVMR®'s Carbonyl Process

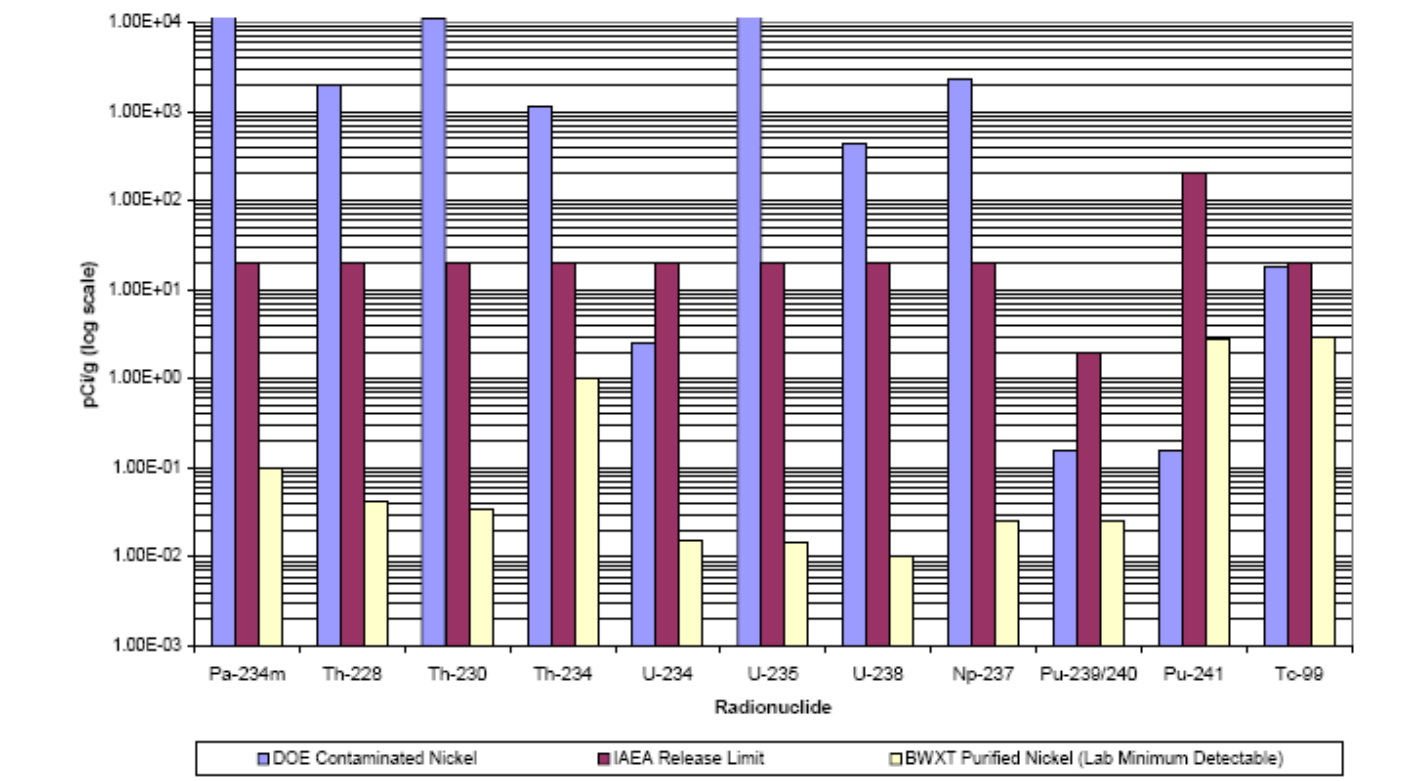
Application to decontamination.
BWXT pilot project



- BWXT pilot project
  - No detectable radionuclide in purified nickel
  - Initial contamination U – 700 ppm, 3.8 ppm, also Th, Np and Pu.

CVMR®'s Carbonyl Process

BWXT pilot project. Results



No detectable radionuclides were found in purified nickel.
Work was done in ORNL facility of BWXT using CVMR's pilot plant.

CVMR®'s Carbonyl Process Application to decontamination.

Description of the project in the white paper submitted to DOE.

A pilot nickel decontamination process was successfully demonstrated on various forms and levels of contaminated nickel. The pilot decontamination process was operated on commercially pure chips at the CVMR facility in Toronto, Canada in December 2004. The equipment was subsequently shipped to BWXT in Lynchburg for the demonstration on various forms of contaminated nickel feed material.

Method	Isotope
γ Spectroscopy (EPA 901.1)	^{54}Mn, ^{60}Co, ^{134}Cs, ^{137}Cs, ^{235}U
α Spectroscopy:	^{229}Th, ^{228}Th, ^{230}Th, ^{232}Th, ^{234}U, ^{235}U, ^{236}U, ^{238}U, ^{237}Np, ^{242}Pu, ^{238}Pu, ^{241}Pu, ^{239}Pu/^{240}Pu ratio
β Spectroscopy (Liquid scintillation)	^{241}Pu, ^{99}Tc

Table 2-2. Isotopic Analysis Method. A full suite of isotopic analyses were performed to verify the purity of the decontaminated nickel.

Decontamination of zirconium spent rods.

- Program goals.
  - To test separation of Nb, Sn and Zr.
  - To produce Zr tubes.
- Proposed chemistry of separation.
  - Al + NbI5 = AlI3+ NbI2
  - 3Zr + 4NbI5 = 3ZrI4+ 4NbI2
  - SnI4 should be distilled out without reaction. SnI4 can be recovered and decomposed to I2 and SnO2

System Modifications.

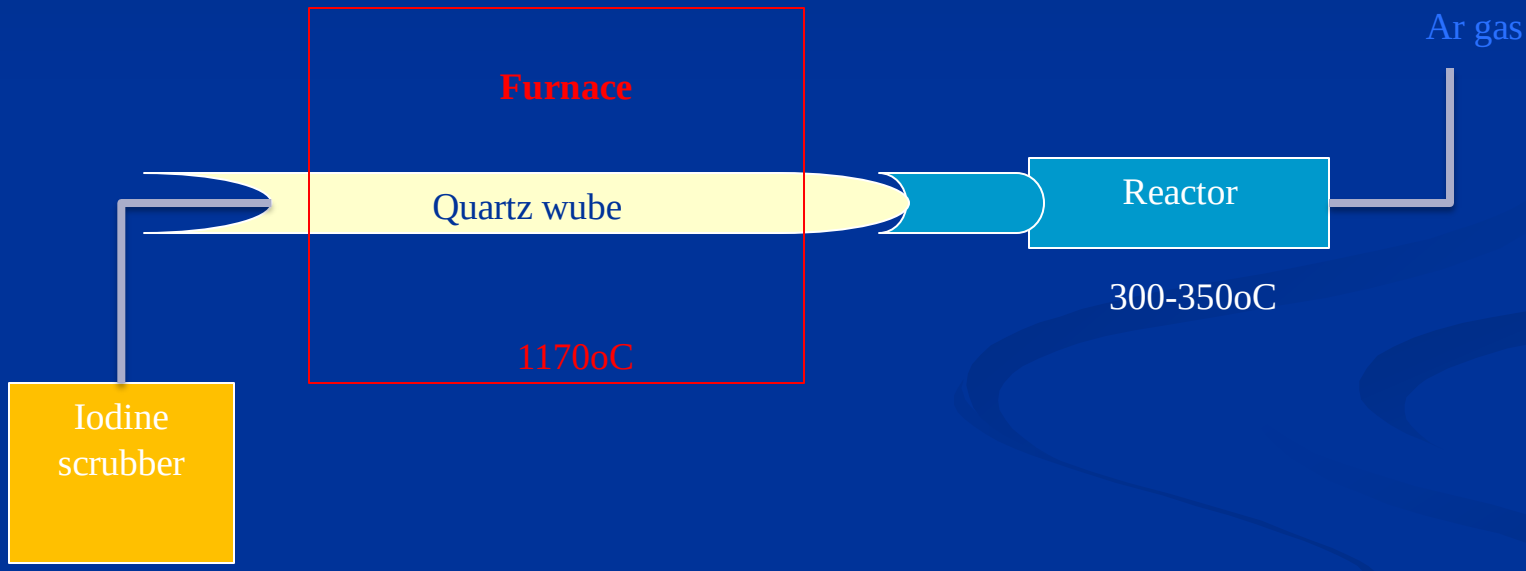


Figure 1: Deposition setup.

Test results.

Name of alloy	Sn (%)	Fe(%)	Cr(%)	Nb(%)	Others
Zircalloy 2	1.45	0.135	0.1	-	
Zircalloy 4	1.45	0.21	0.1	-	Ni(0.055%)
M5	-	0.027	-	0.91	

Test #	Zr %	Nb %	Sn%
1	97.81	0.32	0
2	74.4	BDL	0
3	73.10	0.006	0

Project synopsis

- CVMR is planning to put production facility to produce Nickel, Iron and Cobalt nano powders.
- The plant has to be located in the area with access to a chip feed material, educated labour and developed infrastructure.
- Time line of the project:
  - 8-12 month initial period for setting the structure of the company
  - 4-6 month feasibility study and test work.
  - 4 month permitting and site preparation
  - 12-18 month construction of the plant.
  - 3 years scaling up
- Production capacity – 2000 tons per year of Ni, Fe and Co nano powders.

Project partnership structure.

- CVMR will provide technology, produce feasibility study, build the plant, operate the plant and provide marketing and sells
- Rusnano will provide finances, help in locating proper site for the plant, provide legal support in Russia and introduction to the feed material supplier.
- Feed material supplier will provide long term off take agreement to provide Ni, Fe and Co feed material for the project.